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# Investigating tools to assist dairy farmers in identifying the causes of lameness in dairy cows

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**Abstract**

Foot lesions causing lameness in dairy cows are a major source of production and economic losses and affect the welfare of dairy cows. The literature suggests that dairy farmers often diagnose and treat lame cows without expert opinion or assistance. Although there is a paucity of research regarding dairy farmers' ability to diagnose and treat foot lesions, the high culling rates associated with lameness may indicate poor diagnosis or treatment. Therefore, research into tools to assist dairy farmers in identifying the causes of lameness in dairy cows is a priority. The broad aims of this thesis were to: i) conduct a systematic review of tests described in the literature for the detection of lameness and the diagnosis of foot lesions, ii) determine dairy farmer ability to correctly diagnose and treat foot lesions, iii) investigate the potential for simple mobile phone technology to be used as a remote consultation tool between dairy farmers and veterinarians, and iv) investigate the beliefs underlying dairy farmer intentions to improve their management practices of foot lesions causing lameness.

The systematic review identified a number of tests for the detection of lameness, foot lesions, sole ulcers and digital dermatitis. No tests were identified for the diagnosis of specific foot lesions. Key objectives of this study were to assess the methodological quality of the included studies, compare the performance of the identified tests using reported sensitivity and specificity values, and subsequently make recommendations regarding suitability for implementation on farm. However, none of the tests reviewed and assessed could be recommended due to incomplete reporting of pertinent information and significant risk of bias in all studies. A key recommendation from this study is that authors of future studies in this field should use the STARD guidelines. This would enable thorough evaluation of future tests.

Data were acquired from a previously conducted observational study to determine dairy farmer ability to correctly diagnose and treat foot lesions and to introduce the concept of a tele-foot-health system, where digital images of foot lesions were sent to a remote veterinarian for assessment. Diagnostic agreement was assessed between two sets of raters, an on-site (farm) veterinarian and a dairy farmer and the farm veterinarian and a remote veterinarian, for four criteria: body region, tissue, diagnosis and treatment. Overall, the farm veterinarian and dairy farmer demonstrated weak to almost perfect agreement, whereas the farm veterinarian and remote veterinarian demonstrated moderate to almost perfect agreement. For the farm veterinarian and dairy farmer, weak levels of agreement for diagnosis and treatment suggest that the dairy farmer may need more assistance in

diagnosing and treating the foot lesions occurring in their herd. The moderate to almost perfect agreement achieved between the farm veterinarian and remote veterinarian indicates the potential for success of the proposed tele-foot-health system. More research is needed to further investigate and validate its use.

The final research chapter used a questionnaire based on a social–psychology framework, the Theory of Planned Behaviour. In brief, such studies identify individuals' key behavioural, normative and control beliefs in relation to the behaviour of interest and assess the associations between the beliefs and intention to perform the behaviour. This study identified that dairy farmers believed improving their current management practices of foot lesions would improve animal welfare, increase milk production and was worth the cost involved (behavioural beliefs). Dairy farmers indicated that the opinions of consumers, staff, and animal welfare groups were important in their decision to make improvements (normative beliefs). Better equipment and facilities, improved knowledge and training, and a favourable cost benefit ratio were perceived as factors that would enable dairy farmers to improve their management practices (control beliefs). While all of these beliefs may be considered as potential drivers to facilitate positive behavioural change, the behavioural beliefs were identified as the priority beliefs that industry should target in the development of strategies to increase dairy farmer intentions to make improvements to their current management practices of foot lesions.

This thesis has demonstrated that dairy farmers need support for diagnosing the foot lesions that affect the dairy cows in their herds. While no tools of this nature currently exist, the tele-foot-health system introduced in this thesis offers a possible solution to assist dairy farmers in both the diagnosis and treatment of foot lesions. However, further research is required to fully support its implementation on the farm. To support the uptake of tools like this, this thesis demonstrates the importance of targeting dairy farmer behavioural beliefs in the development of strategies to promote improved dairy cow foot health. In conclusion, this thesis has provided direction for further research into tools to aid dairy farmers in improving their management of foot lesions causing lameness in their dairy herds.

## Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, financial support and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my higher degree by research candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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## **Publications during candidature**

### Peer-reviewed papers

Dutton-Regester, K.J., Barnes, T.S., Wright, J.D., Alawneh, J.I., & Rabiee, A.R., 2017. A systematic review of tests for the detection and diagnosis of foot lesions causing lameness in dairy cows. *Preventive Veterinary Medicine*, vol. 149, pp. 53-66.

### Conference presentations and abstracts

#### *Oral presentation*

Chaplin, K.J., Barnes, T.S., Wright, J.D., Avila, A.A. and Alawneh, J.I., *A hoof telehealth system: using mobile phone image capture technology to remotely diagnose lameness lesions in dairy cows.* 14th International Symposium on Veterinary Epidemiology and Economics, 2015. Merida, Yucatan, Mexico

#### *Poster presentations*

Kate J. Chaplin, John D. Wright, Ahmad R. Rabiee, Tamsin S. Barnes, 2016, *Using the theory of planned behaviour to understand dairy farmer intentions to make improvements to their management of foot lesions causing lameness in dairy cows*. SVS conference, Gatton, QLD

Kate J. Chaplin, John D. Wright, Ahmad R. Rabiee, Tamsin S. Barnes, 2016, *Using the theory of planned behaviour to understand dairy farmer intentions to make improvements to their management of foot lesions causing lameness in dairy cows*. QAAFI Animal Science Olympics

## **Publications included in this thesis**

No publications included.

## Contributions by others to the thesis

Dr John Alawneh (The University of Queensland, School of Veterinary Science, Gatton, Queensland) was my principal advisor from June 2014 to June 2015. He was involved in the design and structure of the thesis and provided the data for Chapter 4. These data were provided already extracted from the original data collection forms used in the study and transferred into an excel file. Dr John Alawneh was involved in initial discussions involving the analysis of these data and early drafts of the chapter. During my candidature there was a change in my advisory team with Dr John Alawneh leaving the team. Due to these changes, there was no further input from Dr John Alawneh.

Dr Tamsin Barnes (The University of Queensland, School of Veterinary Science, Gatton, Queensland) was my principal advisor from June 2015 to completion of my thesis. Prior to taking on this role, Dr Tamsin Barnes was an associate advisor. Dr Tamsin Barnes played a major role in understanding and determining the best approach for statistical analysis of the data provided for Chapter 4. In addition, she provided ongoing guidance in the interpretation of the results. Dr Tamsin Barnes provided guidance in methodology and interpretation of results for Chapter 5 and critically reviewed all chapters of the thesis.

Dr Ahmad Rabiee (CSA Analytics Australia) was an associate advisor. He provided advice about systematic review methodology and interpretation, in general and specific to the systematic review of this thesis (Chapter 3). He provided guidance on the structure of Chapter 3 and reviewed the data extracted from each included paper. Dr Ahmad Rabiee critically reviewed the systematic review and provided input into and critically reviewed Chapter 5.

Dr John Wright (The University of Queensland, School of Veterinary Science, Gatton, Queensland) was an associate advisor. He provided expert advice on the clinical aspects of foot lesions and lameness in dairy cows and also critically reviewed all thesis chapters. Dr John Wright interviewed 20 dairy farmers for the initial elicitation study for Chapter 5 and provided guidance in methodology and interpretation of results of this chapter.

**Statement of parts of the thesis submitted to qualify for the award of another degree**

None.

**Research Involving Human or Animal Subjects**

Chapter 3 required participation of animal subjects. Approval prior to undertaking this study was sought from the University of Queensland Animal Ethics Committee. The Approval Number is SVS/082/12. A copy of the ethics approval letter is located in Appendix 10.

Chapter 5 required participation of human subjects. Approval prior to undertaking this study was sought from the University of Queensland Human Ethics Unit. The Approval Number is 2016001140. A copy of the ethics approval letter is located in Appendix 17.

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John (Dick) Wright, also my associate advisor, offered extensive clinical knowledge of lameness and was responsible for ‘harassing’ the local farmers to complete the questionnaire. I sincerely thank you for your efforts in chasing up dairy farmers for both the elicitation and final questionnaires, often travelling to their farms to conduct the questionnaire in person. This chapter would not have been as smooth going without your generous contribution.

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I thank the following organisations for distributing the questionnaire for my third research chapter (Chapter 5): Dairy South Australia, Dairy New South Wales, AusDairyL, Scibus, North Coast Fresh Food & Cold Storage Co-operative Company (NORCO), Dairy Farmers Milk Co-operative, and South-Coast and Highlands Dairy Co-operative. Without their support in distributing the questionnaire, this chapter would not have been possible.

Thank you to the RSPCA for providing me with the Humane Animal Production Research scholarship. These funds enabled me to purchase statistical software, present my work at two conferences in poster format, and purchase a much-needed new laptop to complete this thesis.

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**Keywords**

dairy cows, lameness, foot lesion, dairy farmers, systematic review, inter-rater agreement, theory of planned behaviour, tele-medicine

**Australian and New Zealand Standard Research Classifications (ANZSRC)**

ANZSRC code: 070703, Veterinary Diagnosis and Diagnostics, 10%

ANZSRC code: 070704, Veterinary Epidemiology, 80%

ANZSRC code: 170202, Decision Making, 10%

**Fields of Research (FoR) Classification**

FoR code: 0707, Veterinary Sciences, 90%

FoR code: 1799, Other Psychology and Cognitive Sciences, 10%

**Dedication**

This thesis is dedicated to my friend, my love, my life, Ken (Dr Ken). This has been a long and tough journey and Ken has witnessed it all. He has been my shoulder to lean on when things got tough (again and again), but he has also been the one to keep me standing tall through these times and to the end of this journey. Ken, without your love and support, and particularly your help around the home in the final few months, completion of this thesis would not have been possible.

And to our little baby Ty, who arrived a few weeks early, then patiently waited for me to complete this thesis. Now, all of my time can be with you.

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## List of abbreviations

| | |
|---|---|
| Att | Attitude |
| AUD | Australian dollar |
| BAK | Bias adjusted kappa |
| BI | Bias index |
| bs | Behavioural belief strength |
| $bs_i$ | The $_i$th outcome of behavioural belief strength |
| cp | Control belief power |
| $cp_k$ | The $_k$th factor of control belief power |
| cs | Control belief strength |
| DF | Dairy farmer |
| DIM | Days in milk |
| DTA | Diagnostic test accuracy |
| EBM | Evidence based medicine |
| FN | False negative |
| FP | False positive |
| FV | Farm veterinarian |
| Hn | The nth hypothesis |
| ICC | Intra-class correlation coefficient |
| IRT | Infra-red thermography |
| *k* | Cohens kappa coefficient |
| LCS | Locomotion scoring |
| LCSS | Locomotion scoring system |
| LR- | Negative likelihood ratio |
| LR+ | Positive likelihood ratio |
| max *k* | Maximum kappa |
| mc | Motivation to comply |
| MMS | Multi-media messaging service |
| NA | Not applicable |
| NPV | Negative predictive value |
| NR | Not reported |
| ns | Normative belief strength |
| $ns_j$ | The $_j$th referent of normative belief strength |
| oe | Outcome evaluation |

| | |
|---|---|
| PABAK | Prevalence and bias adjusted kappa |
| PBC | Perceived behavioural control |
| Pe | Expected agreement |
| PI | Prevalence index |
| Pneg | Percent negative agreement |
| $P_o$ | Overall percent agreement |
| PPos | Percent positive agreement |
| PPV | Positive predictive value |
| QUADAS | Quality assessment of diagnostic accuracy studies |
| $r_s$ | Spearman rank correlation coefficient |
| RV | Remote veterinarian |
| Se | Sensitivity |
| SN | Subjective norm |
| Sp | Specificity |
| STARD | Standards for the reporting of diagnostic accuracy studies |
| TN | True negative |
| TP | True positive |
| TPB | Theory of planned behaviour |
| USD | United states dollar |
| w*k* | Weighted kappa |

# 1. Chapter 1: General Introduction

Lameness causes significant economic burden to individual dairy farmers and the dairy industry and compromises dairy cow welfare. Lameness may be caused by any of a large number of lesions. These lesions can affect the foot, hoof or limb of the dairy cow. The literature suggests that dairy farmer perception towards and ability to detect lameness can be poor. However, little research has investigated dairy farmer ability to correctly diagnose and treat foot lesions causing lameness. The literature indicates that dairy farmers typically diagnose and treat lameness lesions independently without expert advice. Therefore, research invested towards investigating tools to assist dairy farmers in identifying the causes of lameness in dairy cows is considered essential to improve quality of care for lame dairy cows. The overall aims of this thesis were therefore to: i) identify tests that have been investigated in the literature for the detection of lameness and the diagnosis of foot lesions in dairy cows, ii) determine which tests can be recommended for implementation on the farm based on test accuracy and practicality for use by dairy farmers, iii) determine dairy farmer ability to correctly diagnosis and treatment of foot lesions, iv) assess the efficacy of mobile phone technology as a remote consultation tool to facilitate accurate diagnosis and treatment of foot lesions, and v) investigate the underlying beliefs influencing dairy farmer intentions to improve their current management practices of foot lesions causing lameness.

## 1.1. Synopsis and structure of the thesis

This thesis begins with a literature review (Chapter 2) consisting of five sections to discuss the literature relevant to each research chapter. The first section provides an overview of lameness in dairy cows. This review will not cover the aetiology of lameness in detail, nor the numerous lameness lesions that cause lameness as this is beyond the scope of this thesis. This section aims to present the underpinning importance of lameness by discussing the associated economic and welfare implications it contributes to. The second section discusses dairy farmer detection of lameness, diagnosis and treatment of foot lesions causing lameness and dairy farmer perceptions towards lameness. The third section discusses the various statistical analyses presented in the literature that have been applied to studies of observational agreement between two raters. The fourth section provides an introduction to tele-medicine, a form, of remote health care. Finally, section five discusses the psychological framework, the Theory of Planned Behaviour, and how it will be used in this thesis.

Three research chapters follow. Chapter 3 is a systematic review. The objectives of this chapter were to: i) identify tests that have been investigated for the detection of lameness and the diagnosis of foot lesions in dairy cows, ii) evaluate the methodological quality of the studies investigating the identified tests, iii) compare the accuracy of the tests, and iv) determine which tests can be recommended for implementation on the farm. Chapter 4, an observational study, had two main objectives. These were to: i) investigate dairy farmer ability to diagnose and treat foot lesions in dairy cows, and to ii) investigate the use of tele-medicine on the dairy farm by using simple mobile phone technology. Chapter 5 uses the psychological framework, the Theory of Planned Behaviour to: i) explore dairy farmer beliefs, ii) determine dairy farmer intentions and iii) identify opportunities to increase dairy farmer intentions to improve their current management practices of foot lesions causing lameness in dairy cows**.** A discussion of the significance of the key findings of this thesis is presented in Chapter 6, along with recommendations for future research.

# 2. Chapter 2: Literature Review

## 2.1. An overview of lameness in dairy cows

### 2.1.1. The definition of lameness

Lameness may be defined as ‘a departure from normal gait’ (US National Library of Medicine 2017b). In the dairy cow, lameness may involve one or more of the limbs and vary in severity from subtle pain or tenderness to an obvious non-weight-bearing gait, often observed as limping (O’Callaghan 2002). Other observable signs of a lame cow include arching of the back, leg shifting, shortened stride, and head bobbing up and down while walking (Whay et al. 2003). In extreme cases, the affected cow may become fully recumbent and unable to rise (Whay et al. 2003). Therefore, lameness itself is not a disease but rather a clinical sign occurring as a result of injury or disease to any of the structures involved in locomotion.

### 2.1.2. Lesions causing lameness

There are a number of lesions (any pathological or traumatic discontinuity of tissue or loss of function of a part (Blood & Studdert 1999)) that can cause lameness in the dairy cow. These lesions are often found on the lateral claw of the hind foot (Table 2-1). Table 2-2 displays the most frequently identified lesions as reported in a number of studies. The table should be interpreted with regard to the inevitable heterogeneity across studies due to the diversity of farming practices and differences in study methodology. Only two studies (Jubb & Malmo 1991, Chesterton 2008) were identified as using cows kept predominantly at pasture. Therefore, it is difficult to draw conclusions regarding common lesions of these cows. Most studies were from the northern hemisphere, where cattle are commonly kept indoors with little or no access to pasture. The most frequent lesions identified in these cows were sole ulcer, digital dermatitis and diseases of the white line (white line disease and white line abscess) (Table 2-2).

Table 2-1: The location of lesions causing lameness in dairy cows.

| Author (year) | Country | Unit of analysis | No. of units | Lesions identified in the foot (%)[1] | Lesions identified in the hind feet (%)[2] | Lesions identified in the hind lateral claw (%)[3] |
|---|---|---|---|---|---|---|
| Prentice and Neal (1972) | UK | Clinical lameness cases | 369 | 92 | 82.5 | NR |
| Russell and Rowlands (1982) | UK | Total lesions | 9,178 | 88.3 | 84 | 85 |
| McLennan (1988) | Australia | Total lesions | 214 | 83 | 65 | 63 |
| Jubb and Malmo (1991) | Australia | Total lesions | 783 | 91 | 79 | NR |
| Murray et al. (1996) | UK | Total lesions | 8,645 | NR | 92 | 65 |
| Chesterton et al. (2008) | NZ | Total lesions | 2,388 | 85 | 71 | 74 |
| Somers and O'Grady (2015) | Ireland | Lame cows | 134 | 100 | 90 | 98 |

NR: Not reported, UK: United Kingdom, NZ: New Zealand, [1]percentage of number of units, [2]percentage of lesions identified in the foot, [3]percentage of lesions identified in the hind feet.

Table 2-2: Frequency of the three most commonly identified foot lesions causing lameness in dairy cows from a selection of studies.

| Author (year) | Country | Lesion 1 | Frequency (%) | Lesion 2 | Frequency (%) | Lesion 3 | Frequency (%) | Unit of analysis | No. of units | Housing system |
|---|---|---|---|---|---|---|---|---|---|---|
| McLennan (1988) | Australia | Footrot | 15 | Deep sepsis | 9 | Axial groove fissure & white line disease | 8 & 8 | Total lesions | 214 | NR |
| Jubb and Malmo (1991) | Australia | Axial wall cracks | 22 | Under-run sole | 15 | Footrot | 13 | Total lesions | 783 | Pasture |
| Murray et al. (1996) | UK | Sole ulcer | 28 | White line disease | 22 | Digital dermatitis & sole bruising | 8 & 8 | Total lesions | 8,645 | NR |
| Warnick et al. (2001) | USA | Sole ulcer | 20 | Digital dermatitis[1] | 13 | Abscess | 11 | Lame cows | 925 | Free-stall barn |
| Warnick et al. (2001) | | Foot wart | 51 | Sole ulcer | 17 | Footrot | 14 | Lame cows | 287 | Free-stall barn |
| Cook (2004)[2] | USA | Digital dermatitis | 57 | Sole ulcer | 18 | White line disease | 10 | Total lesions | 1,155 | Free-stall and tie-stall barns |
| Sogstad et al. (2005) | Norway | Heel horn erosion | 38 | Haemorrhage of sole | 20 | Haemorrhage of white line | 14 | Lame cows | 1,114 | Tie-stall barn |
| Sogstad et al. (2005) | Norway | Haemorrhage of sole | 12 | Heel horn erosion | 8 | Haemorrhage of white line | 7 | Lame cows | 537 | Free-stall barn |
| Hernandez et al. (2005) | USA | Laminitis | 54 | Imbalanced claws | 11 | Thin soles | 8 | Lame cows | 131 | Dirt lots |
| Bicalho et al. (2007a) | USA | Sole ulcer | 52 | Digital dermatitis | 20 | White line abscess | 15 | Lame cows | 459 | Free-stall barns |
| Bicalho et al. (2007a) | USA | White line abscess | 38 | Sole ulcer | 31 | Digital dermatitis | 9 | Lame cows | 528 | Free-stall barns |
| Chesterton et al. (2008) | NZ | White line disease | 42 | Sole injury | 29 | Axial wall lesions | 13 | Total lesions | 2,388 | Pasture |
| Katsoulis and Christodoulopoulos (2009) | Greece | Abnormal claw shape | 75 | Dermatitis | 30 | Claw horn disruption | 30 | Total lesions | NR | Concrete or soil, restricted access to pasture |
| De Frain et al. (2013) | USA | Digital dermatitis | 48 | Sole ulcer | 21 | White line disease | 17 | Total lesions | 10,818 | Free-stall barn |

USA: United States of America, NZ: New Zealand, [1] reported as foot wart in paper, [2]conference proceeding.

### 2.1.3. The implications of lameness

#### *Compromised welfare*

A dairy cow has specific needs such as the ability to lay down to rest and ruminate, to move freely, to acquire adequate nutrients and to participate in cow-to-cow interactions. However, lesions causing lameness can inhibit the performance of such behaviours (O'Callaghan 2003; Coignard et al. 2014). The effect of lameness on dairy cow welfare has been extensively documented in the literature; however, there are some conflicting results. These are discussed below.

Ito et al. (2010) and Navarro et al. (2013) found that compared to non-lame cows, lame cows spend less time standing or walking and extended periods of time lying down. Hassall et al. (1993) reported that lame cows grazed for shorter periods than non-lame cows and Hassall et al. (1993) and Walker et al. (2008b) concur that lame cows demonstrated a slower bite rate at pasture. Additionally, Walker et al. (2008b) notes a lower body condition score in lame cows. Hassall et al. (1993) and Walker et al. (2008b) report that lame cows were consistently at the end of the herd when entering and exiting the milking facility, furthermore, Hassall et al. (1993) reported that lame cows appeared more restless on their feet while being milked. Conversely, Walker et al. (2008b) reported that lame cows did not spend less time drinking, grazing, or ruminating when compared to non-lame cows. These finding are consistent with that of Galindo and Broom (2002) who found no differences between lame and non-lame cows in the quantity of time spent lying down, feeding, and standing. They did however, find that lame cows spent less time walking.

These conflicting results may be explained in part by the housing conditions used in each study as different environmental surfaces have been demonstrated to influence the behaviour of lame cows. For example, Ito et al. (2010) found that cows with severe lameness (LCS = 4) spent more time lying down on deep bedded (using sand or sawdust) stalls than those using a mattress. Cook et al. (2004) and Cook et al. (2008) reported that lame cows spent more time standing in stalls than their non-lame counterparts, however, this difference was greater with mattress stalls compared with sand stalls. This is consistent with the findings of Tucker et al. (2003) and Tucker and Weary (2004), reporting that mattress stalls reduce lying time. It is suggested that mattress stalls may impose restrictions on the ability of cows to stand up and lie down, resulting in longer bouts of standing.

Each of these studies should be interpreted with regard to the locomotion scoring system (LCSS) used (Table 2-3) and therefore, the inevitable variation in using these LCSS's due to their subjective nature. However, it is biologically plausible that lame cows, particularly those with painful lesions, would stand, walk and graze for shorter periods of time than non-lame cows, resulting in increased intervals of lying down. A caveat of the studies by Walker et al. (2008b) and Galindo and Broom (2002) is the small sample sizes used (lame cows n=39, non-lame cows n=20 and lame cows n=10, non-lame cows n=10, respectively). This may have resulted in limited power to detect a difference between lame and non-lame cows. Further, observational bias may be present due to the interpretation of behaviour by the observer. While this was minimised by Walker et al. (2008b) who used one experienced observer, the study by Galindo and Broom (2002) used several observers.

Table 2-3: Locomotion scoring systems used by the studies investigating aspects of dairy cow welfare.

| Author | Locomotion scoring system |
|---|---|
| Ito et al. (2010) | Flower and Weary (2009), where: 1 = sound and 5 = severely lame |
| Navarro et al. (2013) | Sprecher et al. (1997), where: 1 = gait is normal and 5 = the cow demonstrates an inability or extreme reluctance to bear weight on one or more limbs |
| Hassall et al. (1993) | Manson and Leaver (1988), where: 1.0 = minimal abduction/adduction, no unevenness of gait, no tenderness; 1.5 = slight abduction/adduction, no unevenness or tenderness; 2.0 = abduction/adduction present, uneven gait, perhaps tender; 2.5 = abduction/adduction present, uneven gait, tenderness of feet; 3.0 = slight lameness, not affecting behaviour; 3.5 = obvious lameness, some difficulty in turning, not affecting behaviour pattern, 4.0 = obvious lameness, difficulty in turning, behaviour pattern affected, 4.5 = some difficulty in rising, difficulty in walking, behaviour pattern affected; 5.0 = extreme difficulty in rising, difficulty in walking, adverse effects on behaviour pattern. |
| Walker et al. (2008b) | Adapted from Sprecher et al. (1997), where: 1 = non-lame, 2 = mildly lame and 3 - 5 = moderately to severely lame |
| Galindo and Broom (2002) | Adapted from Manson and Leaver (1988). The system includes five scores according to abduction or adduction and unevenness of gait in the cow. Scores from 3 to 5 are considered clinically lame. |

### *Reduced milk yield*

A number of studies have demonstrated that lame cows produce less milk than their non-lame counterparts. Reader et al. (2011) reported that cows with a locomotion score (LCS) of 2 (n=84) and 3 (n=16) produced 0.7 and 1.6kg less milk per day, respectively, than cows with a LCS of 1 (n=140). Warnick et al. (2001) investigated two herds in New York. In the first herd, for lame cows (n=1,796), milk production was 1.5kg/day lower after the first two weeks of diagnosis compared to non-lame cows. In the second herd, for lame cows (n=724), milk production was 0.8kg/d lower in the first and second week after lameness was detected and 0.5kg/day lower three weeks after detection. They suggest that the differences between the two herds may be due to the incidence of different lesions that can cause lameness and in the way lame cows were identified and defined between the two herds (lame cows were identified by farm staff in the first herd and farm staff or a professional foot trimmer in the second herd; no specific LCSS or other method of detection was used).

A number of studies have also demonstrated that milk yield decreases before lameness is observable and for a period of time post recovery. Reader et al. (2011) demonstrated that for six to eight weeks before non-lame cows became a LCS of 2 or 3, their daily yield decreased by a mean of 0.5kg and 0.9kg, respectively. Further, the daily yield of cows with a LCS of 2 remained lower by 0.42kg for four weeks after recovery. Green et al. (2002) found that milk yield decreased from four months before until five months after a cow was identified as lame, resulting in a milk loss of 160 to 550 kg over an entire lactation.

As discussed in the previous section, lame cows have been demonstrated to spend less time standing or walking, graze for shorter periods of time, lie down for extended periods of time, and have a lower body condition score compared to non-lame cows. Given this information, it is biologically plausible that lameness would directly interfere with a cow’s dry matter intake and therefore milk yield due to a negative energy balance.

### *Reduced reproductive potential*

A number of studies have demonstrated the various ways in which lameness affects the reproductive performance of dairy cows. Walker et al. (2008b) demonstrated that lame cows (n=39) express behavioural indicators of oestrus with less intensity than non-lame cows (n=20). However, this is due to lame cows spending shorter periods of their daily activity budget to expressing oestrus behaviours rather than their inability to actually perform the behaviours. Walker et al. (2008b) suggests that this may be due to the physical nature of many of the indicators of oestrus which include more vigorous interactions with herd mates such as increased walking and mounting behavior.

Cows spending less time demonstrating oestrus are potentially at risk of extending the calving to conception interval. The studies in Table 2-4 demonstrate that compared to non-lame cows, lame cows have an extended calving to conception interval, ranging from 12 to 40 days longer depending on lesion type, housing system, number of days in milk and the definition of lameness used in the study. In addition, Garbarino et al. (2004) demonstrated that lame cows are susceptible to delayed cyclicity with the incidence reported to be 17% in lame cows (n=41, a cow where an arched-back posture is always evident and gait is best described as one deliberate step at a time. The cow favours one or more limbs/feet), 14% in moderately lame cows (n=101, a cow where an arched-back posture is evident while standing and walking. Cow's gait is affected and is best described as short strides with one or more limbs), and only 6% in non-lame cows (n=96). This delayed cyclicity may also play a role in increasing the calving to conception interval.

Table 2-4: Studies demonstrating an increased calving to conception interval for lame cows.

| Author, year | Difference in calving to conception interval between lame and non-lame cows (days) | No. cows | Housing type | DIM | Lameness threshold value | Lesion type |
|---|---|---|---|---|---|---|
| Collick et al. (1989) | 14 | 854 | Cubicles | ≤ 120 | NR | Overall |
| Collick et al. (1989) | 40 | 854 | Cubicles | 70 – 120 | NR | Sole ulcer |
| Hernandez et al. (2005) | 36 | 499 | Indoor dirt lots | NR | ≥4[1] | Overall |
| Bicalho et al. (2007b) | 30 | 1,762 | Free-stall | ≤ 70 | ≥3[2] | Overall |
| Bicalho et al. (2007b) | 31 | 1,762 | Free-stall | ≤ 70 | ≥4[2] | Overall |
| Alawneh et al. (2011) | 12 | 452 | Pasture | NR | NR | Overall |

DIM: days in milk, NR: not reported; [1]using Sprecher et al. (1997) locomotion scoring system; [2]using a locomotion scoring system where: 1 = normal, 2 = presence of a slightly asymmetric gait, 3 = the cow clearly favoured 1 or more limb (moderately lame), 4 = severely lame, to 5 = extremely lame (non-weight-bearing lame).

### *Economic consequences*

Lameness is considered to be one of the most important health conditions of economic significance affecting the dairy industry (Enting et al. 1997; Ettema et al. 2010). Key factors contributing to the cost of a single case of lameness include: treatment and increased labour costs, accrued costs of fertility implications including prolonged calving to conception interval and increased number of services (Hernandez et al. 2001; Hultgren et al. 2004; Hernandez et al. 2005; Sogstad et al. 2005), reductions in milk yield (Warnick et al. 2001; Hernandez et al. 2002), and forced culling (Esslemont & Kossaibati 1996; Forbes 2000; Whay et al. 2003; Booth et al. 2004).

There is limited published information regarding the economic implications of lameness for Australian dairy herds; however, a report by Irwin and Malmo (1998) suggests that Australian dairy farmers face considerable losses. Taking into consideration the cost of reduced milk production, reduced reproductive performance, increased risk of culling, and veterinary treatment, Irwin and Malmo (1998) estimated that each case of lameness costs the Australian dairy farmer approximately $200-300 (Table 2-5). Based on these data, and using an estimate of 1,900,000 cows in milk and an estimated 8% incidence risk of lameness, Irwin and Malmo (1998) estimate that lameness costs the Australian dairy industry approximately $30-45 million per annum.

In the Northern hemisphere, Enting et al. (1997), Kossaibati and Esslemont (1997), Willshire and Bell (2009), Bruijnis et al. (2010) and Cha et al. (2010) have estimated the cost for a single case of lameness to be fl104, £113, £154, $75USD, $178USD respectively (Table 2-5). This variation in cost is likely due to the definition of lameness considered in these studies, and the variables and values included in their calculations. Furthermore, the variety of lesions that may cause lameness are likely to differ in their severity and duration. For example, Whay et al. (1998) demonstrated that lesions such as foot rot and digital dermatitis are acute in nature with cows returning to a normal pain response quicker than those with more chronic lesions such as white line disease or sole ulcer. Therefore, each type of lesion is likely to have a different impact on treatment and labour costs, milk yield and reproductive performance.

Recognising that the costs associated with lameness are lesion specific, Cha et al. (2010), Ettema et al. (2010), Kossaibati and Esslemont (1997) and Willshire and Bell (2009) reported the estimated cost per type of foot lesion (Table 2-5). Table 2-5 highlights that there is variation in the estimated costs of different lesions with sole ulcer and white line disease being more expensive than digital dermatitis and foot rot. Therefore, in the calculation of the cost of lameness, it is reasonable to conclude that where a particular lesion may incur higher costs (e.g. sole ulcer), if this lesion accounts for a higher proportion of the calculation, an overall cost per case of lameness may be inflated.

### 2.1.1. Summary

Lameness in the dairy cow is a clinical sign occurring as a result of injury or disease to any of the structures involved in locomotion. There are a number of lesions that can cause lameness, these are most frequently identified in the lateral claw of the hind foot. The most frequently identified lesions of dairy cows kept indoors are sole ulcer, digital dermatitis and diseases of the white line (white line disease and white line abscess). There is a paucity of peer-reviewed research of cows kept at pasture to determine the common lesions affecting these cows.

Lameness compromises dairy cow welfare, resulting in less time standing, walking and grazing and extended periods of lying down. This interferes with dry matter intake and therefore milk production due to an energy deficit and reproductive potential due to hormonal imbalances.

There is limited published data estimating the cost per case of lameness in Australian dairy herds. Estimates from the Netherlands, the UK, and the USA vary depending on the definition of lameness considered in the study, and the variables and values included in calculations. Further, there is wide variation in the cost of different lesions that can cause lameness.

Table 2-5: Variables and values considered by various studies in the estimated cost per case of lameness and foot lesions.

| Author, year | Country | Reduced milk production | Labour | Treatment | Veterinarian consultation | Calving interval | Culling | Discarded milk | Extra service | Pregnancy rate | Carcass weight | Other | Lameness or foot lesion | Total cost/case of lameness |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Enting et al. (1997) | Netherlands | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X | X | ✓ | ✓ | Lameness | fl104[1] |
| Kossaibati and Esslemont (1997) | UK | ✓ | ✓ | ✓ | ✓ | ✓ | X | ✓ | ✓ | X | X | X | Lameness | £113 |
| Irwin and Malmo (1998) | Australia | ✓ | X | ✓ | X | ✓ | ✓ | X | X | X | X | X | Lameness | $200-300AUD |
| Willshire and Bell (2009) | UK | X | ✓ | ✓ | ✓ | X | X | X | X | X | X | X | Lameness | £154 |
| Bruijnis et al. (2010) | USA | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X | X | Lameness | $75USD |
| Cha et al. (2010) | USA | ✓ | X | ✓ | X | X | X | X | X | ✓ | X | X | Lameness | $178USD |
| Kossaibati and Esslemont (1997) | UK | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X | Digital dermatitis | £213 |
| Willshire and Bell (2009) | UK | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X | X | X | X | Digital dermatitis | £76 |
| Cha et al. (2010) | USA | ✓ | X | ✓ | X | X | X | X | X | ✓ | X | X | Digital dermatitis | $133USD |
| Kossaibati and Esslemont (1997) | UK | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X | Sole ulcer | £392 |
| Willshire and Bell (2009) | UK | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X | X | X | Sole ulcer | £519 |
| Cha et al. (2010) | USA | ✓ | X | ✓ | X | X | X | X | X | ✓ | X | X | Sole ulcer | $216USD |
| Cha et al. (2010) | USA | ✓ | X | ✓ | X | X | X | X | X | ✓ | X | X | Foot rot | $120USD |
| Willshire and Bell (2009) | UK | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | X | X | X | White line disease | £300 |

UK: United Kingdom; USA: United States of America. fl: Dutch guilder (this was the currency of the Netherlands until 2002. After 2002, the euro was the local currency; AUD: Australian dollar; USD: United States dollar.

## 2.2. The dairy farmer – practices and perceptions

### 2.2.1. The detection of lameness

The observation that a cow is lame is typically the first indication of the presence of a foot lesion. This initial observation is typically performed by the dairy farmer during day-to-day farming practices. However, the literature suggests that the ability of the dairy farmer to observe lameness during day-to-day farming practices is relatively poor. Table 2-6 summarises a number of studies comparing the estimates of lameness prevalence obtained by dairy farmer perception of lameness in their herds and controlled research using an individual trained in locomotion scoring. In each study presented in Table 2-6, data collection for the research reported prevalence was highly structured. The farms were visited on one occasion and cows were locomotion scored by research staff, using a specific definition of lameness, as the cows walked into or out of the milking shed. Conversely, to determine dairy farmer estimation of lameness prevalence, the dairy farmers were asked to, using their own definition of lameness, report how many lame cows they thought there were in their milking herd on the day of the visit. These estimations were taken after the milking session, increasing the potential for recall bias due to the retrospective determination of lameness. However, it is important to note that the prevalence reported by the dairy farmers in these studies may be higher than what she/he would normally estimate given that they may have been aware of the research agenda (i.e., they may have known they would be asked) and therefore may have been paying more attention than normal in the presence of the researchers. According to these studies, research-reported prevalence is consistently higher than farmer-reported prevalence. Therefore, there is evidence to suggest that dairy farmers fail to recognise the true magnitude of lameness within their herds.

### 2.2.2. The diagnosis and treatment of foot lesions causing lameness

In the management of lameness lesions, ultimately, provision of appropriate treatment is key. However, in order to establish appropriate treatment, it is important that an accurate diagnosis is made in the first instance (Balogh et al. 2015). While diagnostic error may result in no consequence, if for example an appropriate treatment is still applied regardless of the diagnosis made, at the other end of the spectrum, incorrect diagnosis may result in further harm to both the cow (e.g., appropriate treatment is delayed, or unnecessary or harmful treatment is applied) and the dairy farmer (e.g., unnecessary financial repercussions) (Singh et al. 2012; Balogh et al. 2015). Therefore, following the detection of a lame cow, it is important that the dairy farmer can identify the cause of the lameness (i.e.

provide an accurate diagnosis) in order to facilitate appropriate treatment. The dairy farmer may choose to act independently or seek assistance from an expert (i.e., veterinarian or other professional). Research focused on the ability of dairy farmers to correctly diagnose the causes of foot lameness in their cows and subsequently provide the most appropriate treatment for that diagnosis is not well documented in the peer-reviewed literature. However, various studies indicate that dairy farmers frequently treat lameness without seeking expert advice or assistance. Whitaker et al. (1983), Fabian et al. (2014) and Horseman et al. (2013) report that only 28% (52/185 farms), 36% (21/59 farms), and 32% (27/84 farms), respectively, of lameness treatment was carried out with the assistance of or solely by a veterinarian. Conversely, Mill and Ward (1994) reported that veterinary assistance was involved in 80% (12/15 farms) of lameness cases. The reason for the lack of veterinary (or other expert) involvement in the treatment of foot lesions in the majority of these studies is unclear. Possible explanations may include: high farmer confidence in their ability to diagnose and treat independently; costs associated with a veterinary consultation; poor accessibility to a veterinarian; increasing herd sizes resulting in time pressures; or, a poor perception of the cost and welfare implications associated with lameness, culminating in a ‘wait and see mentality’.

Table 2-6: Dairy farmer estimate of lameness prevalence compared to the prevalence estimates obtained from controlled research.

| Author, year | No. of herds | No of cows | Research prevalence (%)[1] | Research definition of lameness | No. observers (concordance) | Farmer prevalence (%)[1] | Farmer definition of lameness |
|---|---|---|---|---|---|---|---|
| Wells et al. (1993) | 17 | 1.654 | 13.7[2] | 0-4 scoring system, where: 0: gait abnormality not visible, 1: mild variation from normal gait, 2: moderate and consistent gait asymmetry, 3: marked gait asymmetry, 4: recumbent. A LCS ≥ 2 was considered lame. | 2[4] (0.60) | 5.6 | NR |
| Wells et al. (1993) | 17 | 1,654 | 16.7[3] | 0-4 scoring system, where: 0: gait abnormality not visible, 1: mild variation from normal gait, 2: moderate and consistent gait asymmetry, 3: marked gait asymmetry, 4: recumbent. A LCS ≥ 2 was considered lame. | 2[4] (0.60) | 6.4 | NR |
| Espejo et al. (2006) | 40 | 5,626 | 24.6 | 1-5 scoring system, where: 1: normal locomotion, 2: imperfect locomotion, 3: lame; 4: moderately to severely lame, 5: severely lame. A LCS ≥ 3 was considered lame. | 2[5] (0.77) | 8.3 | NR |
| Leach et al. (2010) | 22 | NR | 36 | 0-3 scoring system, where: 0: sound, 1: imperfect locomotion, 2: lame, 3: severely lame. A LCS ≥ 2 was considered lame. | 4[6] (NA) | 6.9 | NR |
| Šárová et al. (2011) | 14 | 807 | 31 | 0-2 scoring system, where: 0: not lame, 1: moderately lame, 2: severely lame. A LCS ≥ 1 was considered lame. | 1 (NA) | 6 | NR |

[1]Pooled prevalence; [2]summer; [3]spring; NA: not applicable; [4]the researchers visited the farm together; [5]all but three farms used one observer, the remaining three farms used two observers; [6]one of 4 researchers visited each farm.

Horseman et al. (2013) conducted a telephone questionnaire of UK dairy farmers (84 respondents) investigating their treatment protocols for solar (sole) ulcer and white line disease. Although the questionnaire specifically differentiated between the two diseases, 69% of respondents stated they applied the same treatment protocol for both diseases suggesting that respondents: i) could not diagnostically distinguish between the two diseases; or ii) did not distinguish between the two diseases on the basis of treatment and were therefore unaware that each disease has a preferential, albeit subtlety different, treatment protocol.

As the majority of the dairy farmers in the survey reported by Horseman et al. (2013) identified that they treated solar ulcers and white line disease in the same manner, the authors did not identify the range of treatments employed by all respondents but only the treatment (trimming the affected claw and application of a block on the non-affected claw) used by the majority. Horseman et al. (2013) acknowledged that the treatment used by the majority of respondents is that suggested for both diseases in the non-peer reviewed literature, typically performed by veterinarians and recommended by dairy industry bodies. This suggests that the information provided to dairy farmers on the treatment of solar abscess and white line disease does not differentiate between the diseases. Arguably, this is not of significant consequence as it is agreed that treatment of the two diseases is very similar and therefore attempts to educate dairy farmers to diagnostically differentiate between solar abscess and white line disease may add unwarranted complexity without significantly improving treatment outcomes. The alternative argument is that if dairy farmers develop an understanding of the different causes and pathologies of the two diseases, they may be able to take steps to reduce the incidence of the two diseases and be able to obtain better outcomes through the application of more specific, albeit subtle, targeted treatments.

Nonetheless, the choice of treatment may be influenced by the perceived effectiveness or constraints the dairy farmer associates with a particular treatment. Horseman et al. (2013) asked the dairy farmers about the perceived efficacy of four different treatment options for sole ulcer and white line disease. These were: i) trimming affected claws, with 95% of farmers indicating that they have used this treatment; ii) trimming affected claws and applying an orthopaedic block on the unaffected claw, with 92% of farmers indicating that they have used an orthopaedic block; iii) trimming affected claws and giving the animal access to a straw bed, with 70% of farmers indicating that they have placed cows on straw; and, iv) trimming affected claws and administering antibiotics, with 55% of farmers indicating that they have used antibiotics. Only 24% of the farmers considered that trimming the affected claw was always effective; however, 85% considered the treatment practical. Conversely, for trimming the affected claw and applying an orthopedic block, 70% of the farmers considered this treatment effective, and 68% of these farmers considered the treatment practical. Lack of handling facilities, time taken to apply the block, cost, and difficulties getting blocks to adhere were identified as constraints. For trimming affected claws and giving the animal access to a straw bed, 54% found this to be effective; however, practicality dropped to 33%. Finally, for trimming affected claws and administering antibiotics, only 14% found this to be effective; however, practicality rose to 60%. Therefore, dairy farmers frequently use treatments that are easy to administer and manage (i.e. more practical), despite being aware that the chosen treatment is not the most effective treatment option.

### 2.2.3 Dairy farmer perceptions towards lameness

The literature indicates that dairy farmers perceive lameness to be a relatively minor problem in their herds. Leach et al. (2010) reported that while research staff determined the prevalence of lameness to be 36% (average prevalence across 222 farms, range 0-79%), most dairy farmers (90%) did not consider lameness to be a major problem within their herd. Similarly, Bennett et al. (2014) reported that of 163 dairy farmers, 93% did not consider lameness to be a major problem within their herd and Bruijnis et al. (2013) found that of 145 dairy farmers, most reported being content with the current foot health status on their farm. When Leach et al. (2010) asked the dairy farmers what would make them increase efforts to control lameness, the most common response was ‘a bigger problem’. This failure to perceive lameness as a significant issue may be due to the dairy farmer’s definition of lameness, failure to determine all lame cows within their herd, a lack of knowledge of the economic consequences of lameness, or perceiving other health issues as more important and therefore, the priority placed on lameness is reduced.

Bennett et al. (2014) and Leach et al. (2010) demonstrated a correlation between the ranking given to a health issue (by the dairy farmer) in terms of cost and their motivation to intervene with the health issue. When dairy farmers ranked herd health issues according to cost incurred to their farm, Bennett et al. (2014) reported that of 163 dairy farmers, 27% mentioned lameness as the top or one of the top-ranking conditions. Similarly, Leach et al. (2010) reported that of 205 dairy farmers, 18% mentioned lameness as the top-ranking condition. Conversely, mastitis was ranked as the top-ranking condition by 36% and 42% of dairy farmers, respectively. In terms of intervention, Bennett et al. (2014) and Leach et al.

(2010) reported that most effort by dairy farmers is put into mastitis, 42% and 56% respectively, compared to lameness, 19% and 30%, respectively. This is reportedly attributed to the direct impact that mastitis has on milk yield and therefore the perceived effect that mastitis has on profit (Leach et al. 2010). Therefore, mastitis is perceived as a greater financial threat to the dairy farmer and is a priority concern above lameness.

This perception of lameness is likely to inhibit farmer motivation to improve the management of lesions causing lameness; for where there is no perceived problem, motivation remains low. This is demonstrated by Bruijnis et al. (2013), reporting that farmers who believe their cows to have good foot health have lower intention to implement intervention. Conversely, farmers who believe their cows to have poor foot health have more interest in improving lameness detection and control strategies.

### 2.2.3. Summary

The literature suggests that research reported prevalence of lameness is consistently higher than farmer reported prevalence. However, these studies need to be interpreted with caution as there are differences in the way research and dairy farmer prevalence estimates have been established.

A number of studies indicate that dairy farmers typically perform the treatment of lameness independently without expert assistance. However, the ability of the dairy farmer to independently diagnose and treat lesions causing lameness has not been extensively investigated in the literature. One study identified dairy farmers inability to distinguish between sole ulcer and white line disease, using the same treatment protocol for the two diseases. However, it is acknowledged that the methods mentioned by dairy farmers are those that are suggested in non-peer reviewed literature, typically performed by veterinary surgeons, and recommended by dairy industry advisory bodies. Ultimately, the dairy farmer’s choice of treatment may be a trade-off between what is practical given available resources and what they know to be the most effective treatment.

The literature indicates that dairy farmers perceive lameness to be a minor problem. This may be due to their definition of lameness, failure to determine all lame cows within their herd, or a lack of knowledge of the economic consequences of lameness. This perception of lameness has the potential to inhibit dairy farmer motivation to improve the management of lameness.

## 2.3. Measuring the level of agreement between raters

### 2.3.1. Introduction - What is inter-rater agreement?

Inter-rater agreement refers to the level of agreement (concordance) between raters who each classify *N* items into *C* mutually exclusive categories (Kraemer et al. 2002). Unlike studies of diagnostic test performance, in studies of inter-rater agreement, the comparison is not relative to a gold standard, but rather whether the two raters agree with each other. For example, if two veterinarians are asked to classify dairy cows as lame or not lame, a judgement regarding their ability can be achieved by comparing their classification choice with each other to test agreement (Figure 2-1). The results of each rater are tabulated in a 2 x 2 matrix (Table 2-7).

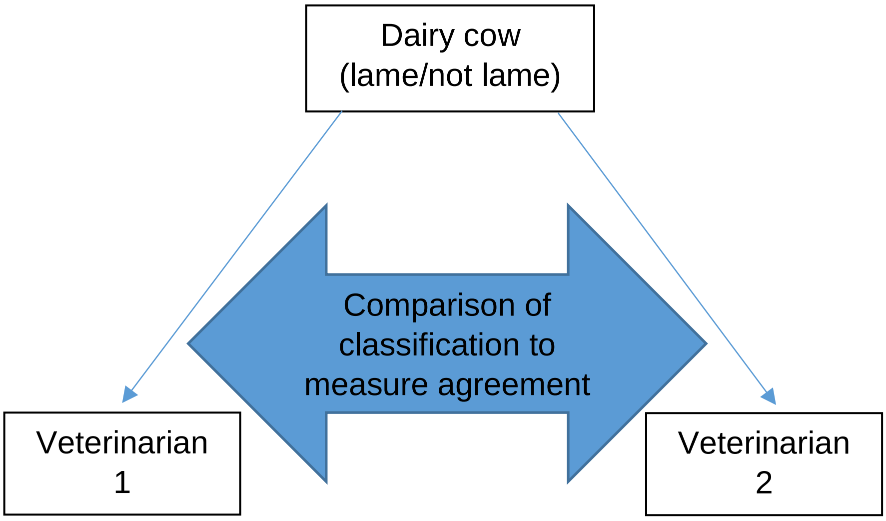


Figure 2-1: The assessment of inter-rater agreement between two veterinarians.

Table 2-7: Summary of binary ratings by two raters in 2 x 2 matrix, where: a = both veterinarians have determined cows as lame, b = rater 1 has determined cows lame, rater 2 has determined cows non-lame, c = rater 2 has determined cows lame, rater 1 has determined cows non-lame, d = both veterinarians have determined cows are lame, N = total number of cows.

| | Rater 2 | | |
|---|---|---|---|
| Rater 1 | + | - | Total |
| + | *a* | *B* | *a+b* |
| - | *c* | *D* | *c+d* |
| Total | *a+c* | *b+d* | *N* |

There are a number of different approaches presented in the literature regarding the analysis of inter-rater agreement data. This has proven confusing to authors new to such studies and has manifest as lack of consistency in the literature and failure to report all necessary information. Therefore, the aim of this section is to describe and discuss the statistical methods available for the analysis of inter-rater agreement as relevant to the aims of this thesis. The focus will be on categorical data between two raters and will include dichotomous (e.g. disease/no disease), ordinal (e.g. disease severity: low, medium or high), and multi-categorical (e.g. foot lesion classification: white line disease, sole ulcer, digital dermatitis or foot rot) data.

### 2.3.2. Statistical approaches for the assessment of inter-rater agreement

*Dichotomous data*

There are four major approaches presented in the literature for the assessment of inter-rater agreement of dichotomous data between 2 raters:

- Proportions of agreement (proportion of overall agreement ($p_o$), percent positive agreement (PPos) and percent negative agreement (PNeg)).
- Cohen's (un-weighted) kappa coefficient (*k*).
- Additional supporting statistics for Cohens kappa coefficient.
- Assessment of marginal homogeneity using the McNemar test, followed by *k.*

#### i) Proportions of agreement

Given two raters, rater 1 and rater 2, the proportion of overall agreement ($p_o$) (also referred to as observed agreement or percentage agreement) is the proportion of cases for which raters 1 and 2 agree (Byrt et al. 1993). Using the notation in Table 2-7, this is simply calculated as a+d/N (Byrt et al. 1993). Proportion of overall agreement offers a useful 'common sense' descriptive statistic, albeit a very crude measurement of inter-rater agreement. It is measured on a scale of 0 to 1 and is often reported as a percentage (McHugh 2012). However, reported independently, $p_o$ presents limitations (Uebersax 2015). The first is that it does not distinguish between agreement on positive and negative ratings (Uebersax 2015). For example, consider two raters classifying a rare disease of very low prevalence as present (positive) or absent (negative). Given the low prevalence of the disease, we would not expect a large number of positive responses, but a large proportion of negative responses. This would result in a very high $p_o$, potentially greater than 0.99, however, this would be due almost entirely to agreement on disease absence (Kundel & Polansky 2003). Therefore, we are not correctly informed as to whether raters agree. To address this issue, we can quantify agreement on positive ratings and agreement on negative ratings using percent positive agreement (PPos) and percent negative agreement (PNeg) (Cicchetti & Feinstein 1990). These are calculated by dividing the number of positive (or negative) ratings observed by the mean number of positive (or negative) ratings (Cicchetti & Feinstein 1990). Similar to $p_o$, PPos and PNeg are measured on a scale of 0 to 1 and are often reported as a percentage (Uebersax 2015).

### ii) Cohen's (un-weighted) kappa coefficient

In studies of inter-rater agreement, raters may agree (or disagree) simply by chance (Sim & Wright 2005). Given this chance agreement, it is important that the statistical analysis quantifies the level of agreement beyond what would have been expected by chance alone. The proportions of agreement previously described do not take chance agreement into consideration. The most widely used statistic for this purpose is Cohens (un-weighted) kappa coefficient (*k*) (Byrt et al. 1993).

Cohen's unweighted kappa coefficient is a chance-adjusted measure of agreement, where *k* assumes all types of disagreement are equally serious (Cohen 1960). The calculation of *k* is based on the difference between $p_o$ and expected agreement ($p_e$), where $p_e$ is the hypothetical probability of chance agreement (Equation 1) (Viera & Garrett 2005):

$$k = p_o - p_e / 1 - p_e$$

Therefore, *k* is the proportion of agreement that is actually observed between raters (Cohen 1960). The value of *k* is measured on a scale of -1 to 1 where 1 is perfect agreement, 0 is agreement equal to chance and a negative value indicates disagreement (McHugh 2012). There are a number of recommendations for the interpretation of *k*, each arbitrary. A commonly cited interpretation is that by Landis and Koch (1977) (Table 2-8).

Table 2-8: The interpretation of kappa values according to Landis and Koch (1977).

| Kappa value | Interpretation |
|---|---|
| ≤ 0.20 | Poor |
| 0.21 0.40 | Fair |
| 0.41 0.60 | Moderate |
| 0.61 0.80 | Good |
| 0.81 1.00 | Very good |

McHugh (2012) argues that the interpretation provided by Cohen (1960) is not satisfactory as it allows a score as low as 0.41 to be considered adequate agreement. McHugh (2012) rationalizes that when agreement is 0.41, 0.59 of the data are incorrect. Further, when *k* values are less than 0.60, the confidence intervals become wider, suggesting that approximately half the data may be incorrect. Therefore, McHugh (2012) provides an alternate interpretation of *k* which categorises any *k* value below 0.60 as insufficient agreement between raters (Table 2-9).

Table 2-9: The interpretation of kappa values according to McHugh (2012).

| Kappa value | Interpretation |
|---|---|
| 0 - 0.20 | Poor |
| 0.21 - 0.39 | Minimal |
| 0.40 - 0.59 | Weak |
| 0.60 - 0.79 | Moderate |
| 0.80 - 0.90 | Strong |
| 0.90 – 1.00 | Almost perfect |

Although *k* is considered a more robust measurement of agreement than proportions of agreement, concern has been raised regarding the use of *k* as a single measure of agreement (Cicchetti & Feinstein 1990). This is because *k* is highly dependent on the symmetry (or marginal distributions) of a 2 x 2 matrix. This describes how the raters separately allocate subjects to the available categories of the 2 x 2 matrix (Banerjee et al. 1999). The term ‘the kappa paradox’ has become a well-documented phenomenon in the literature. This paradox describes two caveats of *k*, each having the potential to result in a misleading *k* value. The first concerns bias between raters where the two raters differ in their selection of categories (Byrt et al. 1993). This causes discrepancies between the marginal totals where they become unbalanced and it is said that there is marginal heterogeneity (Byrt et al. 1993). Bias increases as marginal totals become more dissimilar (Sim & Wright 2005). The second caveat concerns the sensitivity of *k* to the prevalence of the condition in the population. This prevalence effect occurs where the observed ratings fall at a higher rate in one category relative to another resulting in a skewed distribution (Byrt et al. 1993). In this case, agreement expected by chance increases and the magnitude of kappa reduces (Sim & Wright 2005). This occurs because the more homogenous a population is, the higher the probability of raters agreeing purely by chance (Burn & Weir 2011).

The *k* paradox has been responsible for ongoing conflict in the literature regarding both the appropriateness of *k* and the methods to use when bias and/or prevalence are present (Kraemer et al. 2002). Some authors recommend avoiding the use of *k* altogether (Krippendorff 2004), others advise a two-step process where the data is first assessed for marginal homogeneity before proceeding to *k* (Zwick 1988; Uebersax 2015), while others advocate the use of additional statistics to be reported alongside the obtained *k* value (Cicchetti & Feinstein 1990; Byrt et al. 1993; Sim & Wright 2005).

### iii) Additional statistics for the interpretation of kappa

The following statistics are available to adjust for the *k* paradox; however, these are currently less commonly used in the literature.

#### Bias and prevalence indices

For a given 2 x 2 matrix it is possible to quantify the extent of bias and prevalence by calculation of bias and prevalence indices. The bias index (BI) is equal to the difference in proportions of the assignment of 'Yes' by the two raters and is calculated using: BI = (b - c)/N (Sim & Wright 2005). The BI takes values from 0 to 1 (i.e. 0 being no bias and 1 being complete bias) (Sim & Wright 2005).

The extent of prevalence can be quantified using the prevalence index (PI). The PI is the difference between the probability of "Yes" and the probability of "No" and is estimated by (a - d)/N (Sim & Wright 2005). The PI takes values from 0 to + 1 and is equal to 0 when "Yes" and "No" are equally likely (i.e. 50% of agreements fall into one category and 50% in the other category) (Sim & Wright 2005) while an index of 1 suggests a homogenous population in which only one of the category's is represented (i.e. all agreements fall into one category). The PI is therefore a reflection of the homogeneity of the population (Burn & Weir 2011). To avoid the prevalence effect, Hoehler (2000) recommends that investigators use study populations that are relatively heterogenous in their makeup (e.g. with trait prevalence of approximately 50%). However, this is often impractical. Other authors therefore suggest that investigators report both $p_o$ and PI alongside *k*, making an *a priori* judgement as to what $p_o$ and *k* values could be considered the minimum thresholds for clinical usefulness in their particular study. Below the set *k* threshold, any result must be considered to be unreliable, regardless of the $p_o$. This allows investigators to distinguish between variables that show genuinely poor agreement and those that achieve poor *k* values because the population was too homogenous for above chance agreement to have been detected.

### Adjusted kappa

Where bias and/or prevalence indices are high, further measures are proposed to re-adjust the original *k* value. These are bias adjusted kappa (BAK), and prevalence and bias adjusted kappa (PABAK) (Byrt et al. 1993; Sim & Wright 2005)

When dealing with only a bias effect, one can calculate a BAK. The BAK value is obtained when the original values of b and c in the original matrix are both replaced by their average, i.e. m = (b + c)/2 (Byrt et al. 1993). To the authors knowledge there is currently no equivalent calculation for the prevalence effect (i.e., PAK). However, where there is a prevalence effect or combined prevalence and bias effect, a prevalence and bias adjusted kappa (PABAK) can be calculated (Byrt et al. 1993; Sim & Wright 2005). In calculating the PABAK not only are b and c replaced by their average as for the BAK calculation, but in addition, a and d by are replaced by their average, n = (a + d)/2 (Byrt et al. 1993). Essentially, the PABAK rescales $p_o$ so that it takes values from - 1 to + 1 and is zero when observed agreement is equal to 50% (Byrt et al. 1993). However, through a series of simulations, Hoehler (2000) demonstrated that *k* should never be adjusted for when the bias or prevalence effect are observed as this results in overestimation of *k*. Further Hoehler (2000) argues that PABAK readjusts for the factors that *k* is designed to control for.

### iv) McNemar test for marginal homogeneity

The McNemar test (McNemar 1947) assesses marginal homogeneity (bias) in a 2 x 2 matrix. The null hypothesis of the test is that the marginal distributions are homogenous (non-bias) (Uebersax 2006c). Marginal homogeneity implies that row totals are equal to the corresponding column totals, or using Table 2-7:

$$(a + b) = (a + c)$$
$$(c + d) = (b + d)$$

However, as the a and the d on both sides of the equations cancel, b = c; therefore the McNemar test is calculated as: $X^2 = (b - c)^2/(b + c)$ (Uebersax 2006b). The null hypothesis is rejected when the marginal totals are not homogenous (i.e., there is marginal heterogeneity and therefore bias) (Zwick 1988). Marginal heterogeneity is considered to be significant when the test statistic is below a level of significance determined *a priori* to analysis (e.g. $p < 0.05$) (Zwick 1988). With the controversy surrounding *k* (particularly regarding the issue of dependence on marginal distributions), Zwick (1988) reasons that an assessment of inter-rater agreement should begin first with an assessment of marginal homogeneity. She suggests that if marginal heterogeneity is not detected, it is appropriate to calculate *k*, however if present, calculation of *k* is inappropriate.

### *Ordinal data*

There are two approaches used in the literature for the assessment of inter-rater agreement of ordinal data between 2 raters:

- Cohen's weighted kappa coefficient (w*k*)
- Prevalence and bias adjusted kappa for ordinal scales (PABAK-OS)
- Intra-class correlation coefficient

#### i) Cohens weighted kappa coefficient

When analysing ordinal data, it is important to retain the ordering of the categories by taking into account the degree of disagreement between observers (Cohen 1968). For example, if the severity of a lameness lesion is measured on a scale of 1 to 5 (1 being not severe and 5 being very severe), disagreement by 1 scale point (e.g., severity score 1 versus severity score 2) is less serious than disagreement by 2 scale points (e.g., severity score 1 versus severity score 3) and so on. To account for the degree of disagreement between observers, a weighted kappa (w*k*) can be used, attaching greater value to large differences than to small differences (Cohen 1968).

Two main methods of weighting are used: linear and quadratic (Sim & Wright 2005). Linear weights are used when the difference between the first and second category has the same importance as a difference between the second and third category and so on (Medcalc 2016). Quadratic weights are used if the difference between the first and second category is less important than a difference between the second and third category, and so on (Medcalc 2016). However, an important caveat of w*k* (and also *k*, discussed under multi-categorical data) is that it depends on the number of categories available for the variable in question (Warrens 2013). As the number of categories increases, the w*k* value tends to decrease (Warrens 2013).

#### ii) Prevalence and bias adjusted kappa for ordinal scales (PABAK-OS)

The *wk*, like *k*, is adversely affected by imbalanced matrices. There are few additional supporting statistics available for the interpretation of *wk*. However, the PABAK-OS is available for calculating inter-rater agreement between two raters using an ordinal scale of three or more categories (Vannest et al. 2016).

### iii) Intra-class correlation coefficient

The intra-class correlation coefficient (ICC), which can be used for two or more raters (Hallgren 2012), assesses rating reliability by comparing the variability of different ratings of the same subject to the total variation across all ratings and all subjects (Uebersax 2006a). There are a number of variants of the ICC (Shrout & Fleiss 1979; Hallgren 2012). The particular variant used will depend on the study design used (Shrout & Fleiss 1979; Hallgren 2012). It is important to use the correct ICC as the different variants can give very different results when applied to the same data (Shrout & Fleiss 1979). Shrout and Fleiss (1979) describe three classes of ICC: Case 1, Case 2 and Case 3.

In Case 1, for each subject to be rated, a rater is randomly selected from a pool of *n* independent raters (Shrout & Fleiss 1979; Uebersax 2006a). Therefore, the raters who rate one subject are not necessarily the same as those who rate another. This design corresponds to a 1-way Analysis of Variance (ANOVA) random-effects model where the target is the only random effect in the model (Shrout & Fleiss 1979). In Case 2, the same set of *n* randomly selected rater's rate each subject (Uebersax 2006a). This design corresponds to a 2-way ANOVA random-effects model where both the target and the rater are random effects (Shrout & Fleiss 1979). Using Case 2 makes it appropriate to make generalisations to the larger population of raters (Uebersax 2006a). In Case 3, the same raters rate each subject; these are the only raters (i.e., they are not a random sample) (Shrout & Fleiss 1979). This design corresponds to a 2-way ANOVA mixed-effects model where the rater is the fixed effect and the subject is the random effect (Shrout & Fleiss 1979). The ICC applies only to the *n* raters in the study and therefore cannot be generalised to the larger population of raters (Uebersax 2006a).

Similarly to w*k*, ICC is also affected by the number of categories of the variable in question. However, ICC is less sensitive and tends to increase rather than decrease (Bloch & Kraemer 1987; Maclure & Willet 1987). However, when using quadratic weights, w*k* and ICC have been demonstrated to be equivalent (Fleiss & Cohen 1973).

#### *Multi-categorical data*

When dealing with multi-categorical data (i.e. an n x n matrix), although $p_o$ can still be applied as described previously, the calculation of *k* is influenced by the number of categories available for the variable in question (Maclure & Willet 1987), adding yet another layer of complexity to the analysis. Kappa for the n x n matrix is the weighted average of the individual *k*'s, where the weighting depends on the prevalence of each category (Maclure & Willet 1987). Therefore, it is quite possible to get an overall *k* that is near zero, even when some of the individual categories are very well measured and vice versa (Kraemer 1992). In short, an overall *k* value may be influenced by one or two individual categories that have poor agreement, potentially leading to misleading *k* values (Kraemer 1992). Therefore, this approach is not recommended (Maclure & Willet 1987). Although there are few examples of the assessment of inter-rater agreement using multi-categorical data, one method has been proposed in the literature:

- Assessment of component dichotomies using Cohens (unweighted) kappa coefficient.

#### i) Assessment of component dichotomies

For an n x n matrix, rather than calculate an overall *k* value Maclure and Willet (1987) and Kraemer et al. (2002) suggest that it is more appropriate to assess each component dichotomy separately. This simply means that each category of the variable is independently tested against all the other categories combined in a 2 x 2 matrix, resulting in several 2 x 2 matrices and individual *k* values. For example, if the question was:

- "What limb is affected by the lameness lesion?"
- Answers: right forelimb, left forelimb, right rear limb, left rear limb.

Then a 2 x 2 matrix is formed using right forelimb versus all other limbs (thus including all responses). This is repeated for each category. Following this, the additional statistics for the interpretation of *k*, along with PPos and PNeg can be calculated as for binary data.

### 2.3.3. Summary

This section has identified a range of statistical methods which have been used to assess inter-rater agreement of dichotomous, ordinal and multi-categorical data between two raters. Currently there is no consensus regarding the most suitable method.

Proportion of agreement and *k* are widely used in the literature for dichotomous data; however, it is clear that they both have limitations. While $p_o$ fails to account for chance agreement, *k* presents issues with bias and prevalence, termed the 'kappa paradox'. Therefore, reporting *k* independently is not only misleading but also insufficient. Reporting *k* alongside $p_o$ and PI ensures transparency and that that *k* values can be interpreted appropriately.

When dealing with ordinal or multi-categorical data, in addition to the 'kappa paradox', a further caveat of *k* is its sensitivity to the number of categories: as the number of categories increases, the *k* value tends to decrease. While weighted *k*, using linear or quadratic weighting, accounts for the degree of disagreement between observers, the resulting *k* value may be lower than anticipated. An alternative is the ICC. While this is also affected by the number of categories, it is less sensitive and tends to increase rather than decrease. However, quadratic weighting of *k* and the ICC have been demonstrated to be equivalent.

For multi-categorical data rather than calculate an overall *k* value it is recommended to assess each component dichotomy separately. Following this, $p_o$ and PI can be calculated as for binary data to facilitate the interpretation of *k*.

## 2.4. An introduction to tele-medicine

### 2.4.1. An old but new era of medicine

Tele-medicine, from the Greek word 'tele' meaning at a distance (Boydell 2000), is a form of remote medicine using techniques and technology to facilitate information transfer between medical professionals and patients separated by distance (Corr et al. 2000; Whited 2001).Tele-medicine is not new to the medical field with *in absentia* health care having antiquitus roots in the form of written letters by telegram or post, telephone conversation and radio broadcast (Boydell 2000; Mars & Auer 2006). However, with advances in technology modern tele-medicine has the capacity to be far more complex.

There are two forms of tele-medicine: i) real-time or synchronous tele-medicine via satellite technology and video-conferencing tools (Whited 2001), and ii) store-and-forward or asynchronous tele-medicine using digital cameras, email, smart phones, and other wireless tools (Whited 2001; Warshaw et al. 2010) to facilitate information transfer.

### 2.4.2. Veterinary tele-medicine

Mars and Auer (2006) suggests that the first application of tele-medicine in the veterinary field dates back to the early 1980's with the use of a trans-telephonic electrocardiogram (ECG) transmitter which facilitated connection between specialist cardiologists at the Animal Medical Centre in New York and a number of veterinarians throughout America.

To investigate the use of tele-medicine in the veterinary field a systematic review was conducted by Mars and Auer (2006) using PubMed and CAB International databases (1951-2005) with the following search strategy: veterinary AND tele-medicine, veterinary AND tele-care, animal AND tele-medicine, animal AND tele-care and veterinary AND email. They reported 23 papers. In addition, a search was conducted using Google Scholar finding two additional papers. Of the total papers (n=25), only two were research based. Mars and Auer (2006) fail to report the number of papers for each form of tele-medicine (synchronous or asynchronous telemedicine), however, they report that tele-ultrasonography, tele-radiology and tele-cytology were the most frequently reported applications in veterinary medicine.

Replication of the search strategy used by Mars and Auer (2006) in PubMed and CAB International (2006 – 30 April 2015) found a total of 562 papers; however, after screening of titles and abstracts, only nine were found to be related to veterinary medicine. Of the nine papers identified, only three were research based (Table 2-10). A Google Scholar search identified no new publications since 2005. This equates to nine papers over nine years in comparison to 23 papers over 54 years. Therefore, there has been an increase in the number of papers published regarding tele-medicine in the veterinary field.

Table 2-10: Replication of the search strategy used by Mars and Auer (2006) to find tele-medicine papers in veterinary medicine, 2006 –April 30th, 2015.

| Author, Year | Title of paper | Research based paper (Yes/No) |
|---|---|---|
| Mars and Auer (2006) | Telemedicine in veterinary practice | No |
| Mills et al. (2007) | Teaching histology to first-year veterinary science students using virtual microscopy and traditional microscopy: a comparison of student responses | No |
| Sims et al. (2007) | Videoconferencing in a veterinary curriculum | No |
| Neel et al. (2007) | Introduction and evaluation of virtual microscopy in teaching veterinary cytopathology | No |
| Kern et al. (2008) | A remotely controlled lightweight MRI compatible ultrasonic actuator for micrometer positioning of electrodes during neuroethological primate research | Yes |
| Poteet (2008) | Veterinary tele-radiology | No |
| Cottam et al. (2008) | Comparison of remote versus in-person behavioural consultation for treatment of canine separation anxiety | Yes |
| Forlani et al. (2010) | The first veterinary telemedicine study group | No |
| Clements et al. (2013) | Dogslife: a web-based longitudinal study of Labrador Retriever health in the UK | Yes |

In contrast to the lack of available literature on tele-medicine in the veterinary field, numerous examples can be drawn from human medicine. A simple search in PubMed (1951 – 30 April 2015) using the MeSH term ‘tele-medicine’ (delivery of health services via remote telecommunications. This includes interactive consultative and diagnostic services) and the term human (tele-medicine AND human) identified 15,568 papers; 6,722 papers from 1951 to 2005 and 8,869 papers from 2006 to April 30, 2015. It is beyond the scope of this review to screen all articles to determine their relevance to human medicine, however, it provides a strong indication of the interest of tele-medicine applied in the human medical field. Medical fields where tele-medicine has been applied include: tele-cardiology, tele-radiology, tele-pathology, tele-psychiatry, and tele-dermatology.

### 2.4.3. The benefits of tele-medicine

The major advantage of tele-medicine is the removal of spatial limitations where both store-and-forward and real-time tele-medicine offer flexibility to both patient and practitioner in allowing each party to communicate information from a convenient location. This has distinct advantages for isolated and remote communities who may not have access to specialist doctors. For example, Corr et al. (2000) demonstrated the efficacy of store-and-forward tele-medicine using digital camera technology and email transfer of radiographs between doctors working in remote hospitals and specialists located in urban locations in South Africa. Store-and-forward tele-medicine has the added advantage of removing temporal limitations, as both patient and practitioner can communicate at a convenient time, which need not be at the same time.

### 2.4.4. The challenges of tele-medicine

#### *Reliability*

Currently there is a lack of reliability studies conducted on the range of tele-medicine fields. The most common form of tele-medicine studied in the literature is store-and-forward tele-dermatology where digital images of skin lesions are sent to a dermatologist via email or multi-media messaging services from a mobile phone.

Table 2-11 reports the concordance between in-person and tele-dermatology consultation from a number of studies, including both store-and-forward and real-time tele-dermatology. In the studies where multiple in-person and tele-dermatologists have participated, each patient was seen by only one of each dermatologist (i.e., each patient was seen by one in-person dermatologist and one tele-dermatologist). Studies using multiple practitioners provide a greater degree of methodological rigor and therefore a greater degree of confidence in the reported results. This is because using a single in-person and a single tele-dermatologist limits the results to the skills and experience of those particular raters and therefore lack generalisability.

All studies have reported $p_o$, while only four have reported *k*. As discussed in Section 2.3.2, $p_o$ does not take chance agreement into account and is therefore a less reliable measure of concordance than *k*. For the studies reporting *k*, no additional supporting statistics such as Ppos, Pneg or prevalence and bias indices were reported and none of the studies reported 2 x 2 tables to aid interpretation. Therefore, it is difficult to make definitive conclusions regarding the level of concordance achieved from these studies.

Table 2-11: Concordance between in-person and tele-dermatology consultation.

| Author, year | Skill level of in-person dermatologist (no. dermatologists) | Skill level of tele-dermatologist (no. of dermatologists) | No. of skin lesions | Proportion of overall agreement | Kappa value |
|---|---|---|---|---|---|
| **Store-and- forward tele-medicine** | | | | | |
| Whited et al. (1991) | Second- or third-year dermatology residents and attending dermatologist, with 1 to 15 years' experience (2). | Dermatologist in private practice, and two academic medical center–based dermatologists with 4 to 6 years' experience (3). | 168 | 54 | 0.63 |
| High et al. (2000a) | Board certified dermatologists (NR) | Board certified dermatologists (NR). | 106 | 81-89[1] | NR |
| Barnard and Goldyne (2000) | Board certified dermatologists with 5 to 24 years' experience (3). | Board certified dermatologists with 3 to 35 years of practice experience (8). | 50 | 77 | NR |
| Du Moulin et al. (2003) | Dermatologists with 2 to 10 years clinical experience (8). | NR (1) | 106 | 54 | NR |
| Chen et al. (2010) | NR | NR | 429 | 48 | NR |
| Heffner et al. (2009) | NR | NR | 135 | 82 | 0.80 |
| Shin et al. (2014) | Specialist dermatologist (1). | Dermatologists with previous experience in tele-dermatology (3). | 100 | 71 | 0.73 |
| Weingast et al. (2013) | Outpatient staff, i.e. residents in training, under close supervision of the board-certified Consultant on duty (NR). | Dermatologists (15). | 299 | 80 | NR |
| **Real-time tele-medicine** | | | | | |
| Nordal et al. (2001) | Dermatologist (1) | Dermatologist (1) | 112 | 72 | NR |
| Lowitt et al. (1998) | Dermatologists, two board certified and two third-year residents Each physician underwent a 45-minute training session (4). | Dermatologists, two board certified and two third-year residents Each physician underwent a 45-minute training session (4). | 130 | 80 | NR |
| Phillips et al. (1998) | Dermatologist (1) | Dermatologist (1) | 107 | 59 | 0.32 |

### *Legal issues*

Veterinary medicine is a regulated profession. For tele-medicine, this raises a number of important issues which may pose limitations for its use in veterinary medicine. These include: the ability to conduct inter-state practice, the existence of a *bona fide* veterinarian-client relationship, and the dispensing of drugs for future use by a client.

#### Inter-state practice

Traditionally in Australia each state and territory has a registration board and veterinarians are required to be registered in each state they work in (Department of Agriculture and Water Resources 2015). However, at the time of writing, Australia is in the process of setting up a national recognition of veterinary registration which will mean that a veterinarian's home state registration will be recognized by all other Australian jurisdictions, allowing veterinarians to practice across state borders (Department of Agriculture and Water Resources 2015). In terms of tele-medicine, this would have the benefit of allowing a veterinarian in Queensland to conduct a tele-medicine consultation with a client in New South Wales and vice versa.

#### Veterinarian-client relationship

As part of being a registered veterinarian, regulations require the existence of a *bona fide* veterinarian-client relationship where the practicing veterinarian has sufficient knowledge of the animal in question to diagnose the medical condition (Bond 2005). The regulations further stipulate that this includes the veterinarian having recently physically seen the animal in need of medical attention (Bond 2005). This may pose limitations to the practice of tele-medicine in veterinary medicine by restricting consultations to only those animals that have recently been seen in person by the veterinarian. However, this caveat could be avoided where a remote veterinarian is in consultation with an on-site veterinarian (i.e., the remote veterinarian may be a specialist providing expert knowledge to both the on-site veterinarian and the dairy farmer).

#### Dispensing of drugs for future use by a client

In practice, regulations do not encourage veterinarians to dispense quantities of drugs to clients for contingency purposes (Bond 2005). However, it is acknowledged that in certain circumstances, such as remote locations, it is appropriate for veterinarians to dispense drugs to clients such as farmers, specifically for recurring medical conditions (Bond 2005). This may complicate tele-medicine consultations where drugs are required to treat the animal in question. The tele-medicine consultation may become redundant where the veterinarian may need to make a house call to administer drugs or the client may need to visit the clinic to collect drugs or engage in a second, in-person consultation.

### 2.4.5. Cost effectiveness

A small number of studies have investigated the cost effectiveness of tele-medicine. The expected cost will vary greatly between disciplines; however, most studies are in the field of tele-dermatology. Table 2-12 reports the estimated cost comparison between in-person and tele-dermatology consultation.

A study by Armstrong et al. (2007) concluded that real-time tele-dermatology was more cost effective than an in-person consultation by $72USD per hour. In comparison Wootton et al. (2000) found that real-time tele-dermatology was more expensive than an in-person consultation by £83. In comparing these two studies, it is important to note the different items included in the respective calculations. First, Wootton et al. (2000) has included social factors (e.g., travel time and patient time lost at work) in the calculation, while Armstrong et al. (2007) has not. Second, Armstrong et al. (2007) had included the hourly compensation for the dermatologist: $487USD for tele-dermatology (this figure was based on four patients per hour), while the hourly compensation for an in-person dermatologist was $153USD. Further, there are important factors to note that were included in the calculation by Wootton et al. (2000) that may have unrealistically inflated the real-time tele-dermatology cost. First, the mean return travel distance (26km) was low. Realistically, tele-medicine is likely to be used in situations where the distance between the dermatologist and patient is much greater. A sensitivity analysis conducted by Wootton et al. (2000) demonstrated a break-even point would be achieved when the return travel distance was increased to 78km. Second, initial equipment costs were incorporated in the analysis and in this case, based on older equipment purchased in 1995. According to Wootton et al. (2000), modern prices for similar equipment have reduced by approximately 40% which would subsequently reduce the overall cost of real-time tele-dermatology. Finally, for the real-time tele-dermatology consultation, the patient was presented to the dermatologist by a general practitioner, opposed to a nurse, which elevated costs (Wootton et al. 2000).

Eminović et al. (2010) reported the cost of store-and-forward tele-dermatology to be higher than in-person consultation by €33. This estimation included equipment costs, which similarly to Wootton et al. (2000), the author recognises that modern equipment is less expensive and thus has the potential to reduce tele-dermatology costs overall. Additionally, the author recognises that the travel distances used in the study were small and suggests that economic benefit is achieved when the travel distance is increased to

75km. Conversely Moreno-Ramirez et al. (2009) found that store-and-forward tele-dermatology was more cost effective than in-person consultation by €49. Moreno-Ramirez et al. (2009) attributes this to the waiting interval experienced by the patient, with 12.3 days for store-and forward tele-dermatology and 88.6 days for an in-person consultation.

### 2.4.1. Patient and physician acceptance and satisfaction

Few studies have investigated patient and physician acceptance of tele-medicine. Those that have, have focused on tele-dermatology, both real-time and store-and-forward.

In a study by Lowitt et al. (1998) using 139 patients to compare satisfaction of real-time tele-dermatology to traditional in person consultation, patient acceptance of both forms was high (97-100% and 99-100%, respectively). The study consisted predominantly of male patients (95%) with an age range of 23 to 85 years old (mean age of 65). Lowitt et al. (1998) reports that the younger patients were more accepting and amenable to tele-dermatology compared to older patients; however, Lowitt et al. (1998) fails to mention at what age the acceptance begins to decline. In total, four dermatologists were used in the study, two of which were board certified and the remaining two were third year residents. Overall, the physicians were highly satisfied with tele-dermatology (in 81% of cases the physicians were satisfied with their ability to examine skin). However, they expressed having greater confidence in their diagnosis with in-person consultation. Lowitt et al. (1998) fails to make a comparison between the confidence levels and acceptance of the technology between the board-certified physicians and the third-year residents which may impact the overall satisfaction rating as board certified physicians are generally likely to be more confident in their assessment due to their advanced training and experience.

Gilmour et al. (1998) found that overall, patients and practitioners were positive towards the use of real-time tele-dermatology. However, there is no comparison of how satisfied patients and practitioners were with in-person consultation. The study consisted of 126 patients with approximately equal numbers of males and females, ranging from three months to 83 years old. Patients filled out a satisfaction questionnaire, ranking a given statement from ‘strongly disagree’ to ‘strongly agree’. In the report there is no breakdown of age groups to demonstrate potential differences between the younger and older generations. Additionally, with patients as young as three months, it is not clear at what age participants filled out the questionnaire independently. As acceptance is likely to vary between individuals, particularly the older generation who may find tele-medicine difficult or unusual, future acceptance studies should demonstrate acceptance per age group.

Table 2-12: Cost comparison of in-person versus tele-dermatology consultation.

| Author, year | Country | Tele-medicine type | Equipment | Preparation of teleconsultations | Evaluation of teleconsultations by dermatologist | Face-to-face visit to skin cancer clinic | Face-to-face visit to dermatologist | Travel time | Patient work time lost | Physician compensation | Staff costs | Waiting period | Travel cost for accompanying person | Cost of operating in-person consultation | Cost of operating tele-dermatology consultation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Armstrong et al. (2007) | USA | Real-time | ✓ | X | X | X | X | X | X | ✓ | ✓ | X | X | $346USD | $274USD |
| Wootton et al. (2000) | UK | Real-time | ✓ | X | X | X | X | ✓ | ✓ | X | ✓ | X | X | £49 | £132 |
| Eminović et al. (2010) | UK | Store-and-forward | ✓ | X | X | X | ✓ | ✓ | ✓ | X | X | X | ✓ | £354 | £387 |
| Moreno-Ramirez et al. (2009) | Spain | Store-and-forward | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | X | ✓ | X | €129 | €80 |

USD: United States dollar.

In a study by Weinstock et al. (2002), 100 randomly selected patients who had participated in a store-and-forward tele-dermatology consultation across various clinics in Maine USA engaged in a phone interview to assess their perception of tele-dermatology. However, similarly to Gilmour et al. (1998), there was no comparison of how satisfied patients were with in-person consultation. For tele-dermatology, overall patient satisfaction ranged from excellent/good (42%), fair/poor (37%) to average (18%); and 75% of patients said that they would recommend tele-dermatology to a friend. Patient responses regarding the capacity of tele-dermatology to treat a skin condition was similarly distributed with 41% regarding the program as excellent/good and 46% rated it as fair/poor. The median time interval between the consultation and phone interview was 14 months (2.5 - 30.5 months), introducing the potential for recall bias, particularly for those who had longer intervals. Of the 19 physicians who completed the survey, 63% rated the overall experience as excellent or good while 21%, 16% and 0% rated the experience as average, fair or poor respectively.

### 2.4.2. Summary

Tele-medicine is a form of remote medicine facilitating information transfer between medical professionals and patients separated by distance. There are two forms: i) real-time or synchronous tele-medicine, and ii) store-and-forward or asynchronous tele-medicine. Over the past 54 years, the literature on tele-medicine has grown in the field of veterinary medicine. However, tele-medicine has yet to become common practice in the industry. This may be due to the regulated nature of the veterinary profession.

There is a paucity of research investigating the reliability, cost effectiveness and patient/physician acceptance of tele-medicine. Most available studies have focused on tele-dermatology. For store-and-forward tele-dermatology, concordance ranges from 54-89% ($p_o$) and 0.63 to 0.80 ($k$). For real-time tele-dermatology, concordance ranges from 59-80% ($p_o$). Studies reporting on the cost effectiveness of tele-dermatology compared to in-person consultation are inconclusive with some studies suggesting that tele-dermatology consultation is more cost effective, while others suggest the reverse is true. Overall, patient acceptance and satisfaction with tele-dermatology is reportedly high. However, many studies fail to assess patient satisfaction with in-person consultation for comparison. Practitioner acceptance is also high; however, some practitioners express having greater confidence in their diagnosis with in-person consultation.

## 2.5. The theory of planned behaviour

### 2.5.1. Understanding and predicting intentions and behaviour

A number of strategies have been recommended to dairy farmers to improve the management of foot lesions causing lameness in their herds. However, it is not known whether dairy farmers have intentions to make changes to their farming practices. Without intentions, adopting change in management practices is unlikely. Developing an understanding of the factors influencing dairy farmers' decisions to adopt change in management practices is crucial to increase the success of future interventions. One approach to studying dairy farmer intentions and behaviour is to use the social psychological framework of the Theory of Planned Behaviour (TPB), an extension of the earlier framework, the Theory of Reasoned Action (TRA).

### 2.5.2. An overview of the theories

The TRA (Figure 2-2) proposes two psychological constructs that collectively, are said to predict an individual's intentions: i) attitude (toward the behaviour), and ii) subjective norm (about the behaviour) (Ajzen 1985). These constructs are antecedent to the construct intention (to perform the behaviour), the most proximate predictor of actual behaviour (Fishbein & Ajzen 1975; Ajzen 1985).

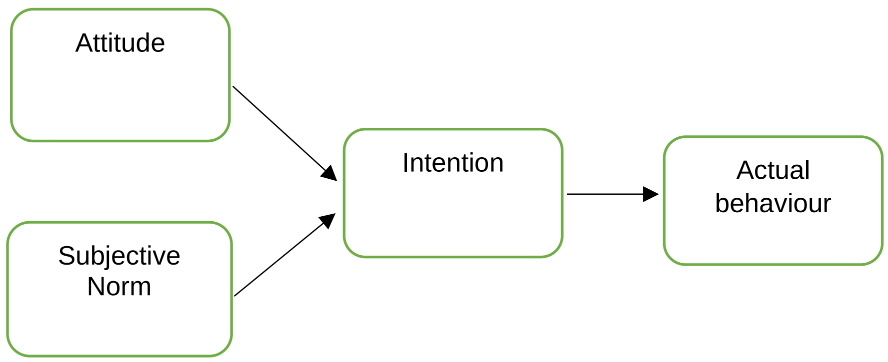


Figure 2-2: Theoretical framework of the Theory of Reasoned Action, adapted from Ajzen 1985.

Attitude measures the degree to which an individual has positive or negative feelings towards the behaviour in question, predicting that the more positive the feelings, the greater the likelihood of engaging in the behaviour (Fishbein & Ajzen 2010). Subjective norm refers to the social pressures an individual may feel, in particular they encompass an individual's perception of whether they should or should not engage in the behaviour in question as seen from his or her significant others (Ajzen 1985). In light of this, the theory predicts that if an individual perceives that his or her significant others would encourage the behaviour, the individual is far more likely to engage in the behaviour and vice versa (Fishbein & Ajzen 1975). Intention is an indication of an individual’s willingness to perform a given behaviour and can be defined as an individual’s ‘subjective probability that he or she will engage in a given behaviour’ (Fishbein & Ajzen 1975). According to the theory, the stronger the intentions, the greater the likelihood that the behaviour will be performed (Fishbein & Ajzen 1975).

The TRA assumes that the behaviour in question is under volitional control (i.e., that individuals perceive that they have a high degree of control over their actions and are therefore capable of performing the behaviour if they choose to do so) (Fishbein & Ajzen 1975). Therefore, the theory is restricted to the application of volitional behaviours. In light of this, the TRA was later extended into the TPB by inclusion of an additional construct, perceived behavioural control (of the behaviour), to consider non-volitional behaviours (Ajzen 1991b) (Figure 2-3). Perceived behavioural control refers to the anticipated ease or difficulty of performing the behaviour in question, predicting that the greater the confidence an individual has that he or she is capable, the more likely the individual will intend to engage in the behaviour (Ajzen 1985).

At a deeper level, the TPB goes beyond predicting an individual’s intention to perform a given behaviour and examines their salient beliefs to understand why they hold the attitudes, subjective norms and perceived behavioural control that they do. An individual may have a number of beliefs relevant to a given behaviour; however, they can only attend to a few at a time (Ajzen 1985). Those few that come readily to mind are referred to as the salient beliefs (Ajzen 1985). Three categories of salient beliefs are identified in the TPB: i) behavioural beliefs (outcomes), the likely consequences of performing the behaviour in question, which are assumed to influence attitude towards the behaviour; ii) normative beliefs (referents), perceptions that particular referents do or do not support the behaviour in question, which are assumed to influence subjective norm; and, iii) control beliefs (factors), perceptions about the presence of factors that facilitate or impede the performance of the behaviour in question, which are assumed to influence perceived behavioural control (Ajzen 1985).

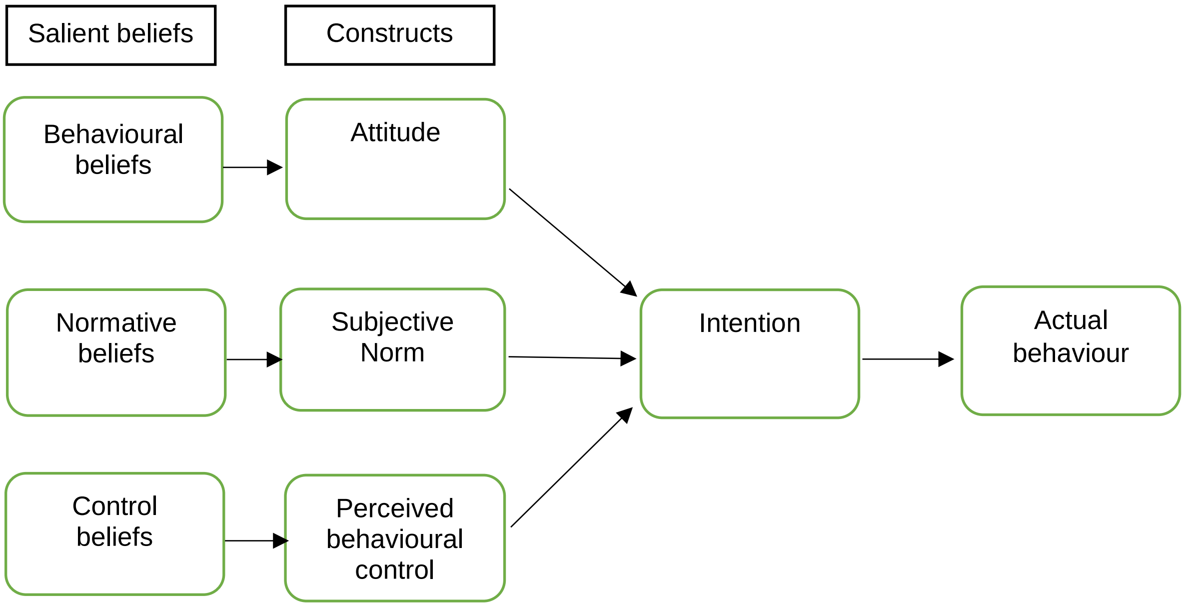


Figure 2-3: Theoretical framework of the Theory of Planned Behaviour, adapted from Ajzen 1985.

### 2.5.3. Sufficiency of the theory

The TPB has been designed as a parsimonious, all-inclusive framework where other potential determinants of behaviour and external factors (i.e., age and gender), are said to be mediated by the constructs already included in the model (Conner & Armitage 1998). Although the theory has proven successful in a wide variety of behavioural studies, it has received criticism due to its parsimonious nature, with many users arguing that not all constructs of relevance are taken into account (Eagly & Chaiken 1993).

A systematic review by Armitage and Conner (2001) demonstrated that the average multiple correlation of attitude, subjective norm and perceived behavioural control with intention was R = .63, accounting for 39% of the variance ($R^2$ = .39). This leaves 61% of the variance in intentions left unexplained. Methodological factors may account for some of the unexplained variance, however, there remains the possibility that the model may be improved by the inclusion of one or more additional constructs (Rivis et al. 2009). Ajzen (1991a) himself indicates that the model in its current state is amenable to the inclusion of additional constructs. However, Ajzen (2011) provides a set of criteria that should be met prior to the addition of a construct. These are:

i) It must be possible to define and measure the proposed construct in terms of the elements: target, action, context and time (TACT). For example, consider the behaviour 'performing locomotion scoring of each cow after they leave the milking parlour in the morning'. Here the target is the cow, the action is locomotion scoring, the context is the clinical condition (lameness) and the time is after morning milking. These elements enable adherence to the principle of compatibility. This principle states that the constructs must be assessed with respect to exactly the same level of specificity to maximise their predictive power (i.e., each construct is assessed at the same level specificity with regard to these four elements).

ii) The proposed construct should be considered as a determinant of intention toward the behaviour in question.

iii) The proposed construct should be conceptually independent of the theory's existing constructs.

iv) The proposed construct should be relevant to a variety of behaviours.

v) Any additional construct must demonstrate the capacity to capture a significant proportion of the variance in intention or behavior after the theory's current variables have been taken into account.

Additional constructs that have been proposed in the literature include: anticipated affect (Rivis et al. 2009), descriptive norms (Conner & Armitage 1998), morals norms (Manstead & Parker 1995), personal norms (Manstead & Parker 1995), past behaviour/habit (Conner & Armitage 1998), and self-identity (Rivis et al. 2009). Currently, there is no consensus on the addition of any of these constructs. In addition, where authors have claimed to show an additional variable has credibility, Aizen and Klobas (2013) and Siegel et al. (2014) claim that the principal of compatibility has not been adhered to correctly. Further it is difficult to fulfill all of the criteria proposed by Ajzen (2011) without a large base of empirical research. Therefore, these additional constructs will not be considered further in this thesis.

#### 2.5.4. Using the theory of planned behaviour to understand and predict farmer intentions and behaviour

The constructs of the TPB are hypothetical or latent variables, therefore, they cannot be directly observed (Ajzen n.d.) However, they can be measured via responses obtained from a number of statements in a questionnaire (Ajzen n.d.). The statements are measured using a 7-point Likert scale (Francis et al. 2004). While there is a standardised method for measuring the construct intention, the literature presents three different approaches to measuring the constructs attitude, subjective norm and perceived behavioural control. These are: i) direct (or global) measures, which ask about overall attitude, subjective norm and perceived behavioural control; ii) indirect (or belief-based) measures, which ask about specific salient behavioural, normative and control beliefs; or iii) a combination of direct and indirect measures. The approach used largely depends on the objectives of the study (Francis et al. 2004). The objectives, strengths and limitations of the three approaches are discussed below. The specific procedures for developing the statements used in a TPB questionnaire will be outlined in detail in Chapter 5 Section 5.2.3.

### *Direct measures*

Direct measures can be used to achieve three objectives: i) to predict intentions and behaviour, ii) to estimate the relative importance of attitude, subjective norm, and perceived behavioural control in predicting intentions and behaviour, and iii) to examine the validity of the TPB framework.

A major advantage of using only direct measures is that the size of the questionnaire can be kept relatively small with a minimum of 12 and a maximum of 24 statements (i.e. 3-6 statements per construct) (Ajzen n.d.), potentially increasing questionnaire response rates.

A potential limitation of direct measures is that some statements may be difficult for respondents to understand. Using a 'think aloud' study (where respondents were asked to verbalize all thoughts that would normally be silent as they completed a TPB questionnaire), French et al. (2007) concluded that, compared to indirect statements, participants were more likely to re-read or struggle when answering direct statements. While fewer problems were identified for the constructs attitude (i.e., only one in five statements appeared problematic to respondents), and perceived behavioural control (i.e., only one in four statements appeared problematic to respondents), the construct subjective norm was the most problematic construct with one in two statements causing difficulty to respondents. This is supported by Darker and French (2009) who also found that statements relating to subjective norm were the most problematic for respondents. French et al. (2007) suggests that in some cases this may have been due to the way the statement was phrased. For example, respondents became confused with how they should respond when they wanted to disagree with a statement that was negatively phrased (e.g., most people whose views I value would disapprove if I was more physically active in the next 12 months). This confusion may be averted by simply avoiding negatively phrased statements.

In other cases, both French et al. (2007) and Darker and French (2009) found that the subjective norm statements lacked specificity. For example, when asked about what ‘important others’ (i.e., the individuals that they considered important to them) would think about the respondent participating in the behaviour, referring to ‘important others’ was difficult to interpret due to the various sub-groups of ‘important others’ that an individual may consider, with each group potentially having a different opinion. Further, statements relating to ‘important others’ were often misinterpreted with participants instead considering whether the opinions of others were important to them, often strongly indicating that they were not. It has been suggested that this may arise due to social desirability bias (the tendency of survey respondents to answer questions in a manner that will be viewed favourably by others) (French et al. 2007). This suggests that being influenced by others is viewed as socially unacceptable. French et al. (2007) and Darker and French (2009) report that where respondents experienced difficulty with the subjective norm statements, they were more inclined to select the neutral option (i.e., neither agree nor disagree), which may prevent the true extent of important others to be recognised.

#### *Indirect measures*

Indirect measures can be used to achieve the same set of objectives as direct measures: i) to predict intentions and behaviour, ii) to estimate the relative importance of attitude, subjective norm, and perceived behavioural control in predicting intentions and behaviour, and iii) to examine the validity of the TPB framework. Additional objectives are to: iv) identify the beliefs that drive intentions and behaviour, and to v) determine the specific beliefs that have the greatest influence on intentions and behaviour.

Using indirect measures offers greater insight into the intentions and behaviour of the target population. However, formulating indirect statements requires a two-step process as the statements are derived from salient behavioural, normative, and control beliefs. These beliefs must first be extracted from a subset of the target population during an elicitation questionnaire (Francis et al. 2004). The elicitation questionnaire is a short, open-ended questionnaire where participants are asked their thoughts, with respect to the behaviour of interest, that come readily to mind in terms of: i) the advantages and disadvantages of performing the behaviour (behavioural beliefs), ii) factors that facilitate or constrain their performance of the behaviour (control beliefs), and iii) individuals or groups that would approve or disapprove of their performing the behaviour (normative beliefs) (Ajzen & Driver 1991). According to the theory, these thoughts are said to be the most salient beliefs held by the population of interest. Analysis of the responses to the above questions results in lists of the most common (modal) salient behavioural, control and normative beliefs that the population holds.

Following this, each salient belief is assessed using the expectancy-value theory (Ajzen 1991a). The expectancy value theory has application in a wide variety of fields including education, marketing, economics and psychology (Fishbein & Ajzen 1975). Although the model differs in its meaning for each field, the overall idea is that there are expectations as well as values that affect the performance of behaviour. In psychology, the expectancy value theory is a function of the interaction between a person's expectations about the outcomes of actions and the value they place on those outcomes (Fishbein & Ajzen 1975). The expectancy-value theory is applied to the TPB as demonstrated in the following equation:

$$B \approx I = y_1 \sum bs_i\, oe_i + y_2 \sum ns_j\, mc_j + y_3 \sum cs_k\, cp_k$$

$$= y_1\, Att + y_2\, SN + y_3\, PBC$$

Where:

| | |
|---|---|
| B | Behaviour |
| I | Intention, intention to perform the behaviour |
| Y | Empirically derived coefficient |
| bs | Behavioural belief strength, a person's perceived probability that performing the behaviour will lead to a particular outcome |
| oe | Outcome evaluation, an individual's subjective evaluation of how good or bad a particular outcome of performing the behaviour is |
| *i* | The $_i$th outcome |
| ns | Normative belief strength, an individual's assessment of whether important referents think he should or should not perform a behaviour |
| mc | Motivation to comply, an individual's assessment of how much s/he wants to comply with the important referents |
| *j* | The $_j$th referent |
| cs | Control belief strength, an individual's assessment of the probability of the belief affecting behaviour |
| cp | Power of the control belief, a person's subjective evaluation of the power of the control belief to affect performance of the behaviour |
| *k* | The $_k$th factor |
| Att | Attitude, an individual's positive or negative evaluation of performing a behaviour |
| SN | Subjective norm, an individual's perception of the social pressures upon him to perform or not perform a behaviour |
| PBC | Perceived behavioural control, perceived ease or difficulty of performing a behaviour |

According to this equation, each behavioural belief identified is assessed in terms of: i) behavioural belief strength, how likely an individual believes that the specified behaviour will result in a certain outcome; and, ii) outcome evaluation, the positive or negative judgements the individual makes about the outcome in question (Ajzen 1991a). Each normative belief identified is assessed in terms of: i) normative belief strength, an individual's judgement of the likelihood that a particular individual or group would support or criticise the performance of the specified behaviour; and, ii) motivation to comply, a judgment of how willing the individual is to adhere to the expectations of others (Ajzen 1991a). Finally, each control belief identified is assessed in terms of: i) control belief strength, the degree to which an individual believes they have control over the behaviour; and, ii) control belief power, how confident an individual feels about being able to perform or not perform the behaviour (Ajzen 1991a). Each component of the behavioural, normative and control beliefs are combined in a multiplicative fashion and the resulting products are summed resulting in the indirect measures of attitude, subjective norm and perceived behavioural control, respectively (Ajzen 1991a).

Using this approach, the size of the questionnaire is dependent on the number of salient beliefs identified and used from the elicitation study. In deciding how many salient beliefs to include, Francis et al. (2004) suggests including a minimum of three for each behavioural, control and normative beliefs while Ajzen and Fishbein (1980) provide the following three options. First, include the ten or twelve most frequently mentioned outcomes. Ajzen and Fishbein (1980) suggest that this is likely to include at least some of the beliefs mentioned by each questionnaire participant. Second, include beliefs that exceed a particular frequency, for example include all beliefs that are mentioned by at least 10 percent or 20 percent of the participants. Or third, choose as many beliefs as necessary to account for a certain percentage (e.g., 75 percent) of all beliefs elicited. Ajzen and Fishbein (1980) suggest that this is the "least arbitrary rule." In considering how many beliefs to include, it is important to consider the overall questionnaire length as increased length increases the risk of participant fatigue or a reduced response rate.

Using indirect measures to achieve the same set of objectives as direct measures is based on the assumption that the direct and indirect measures of a given construct are highly correlated (Ajzen 1991b). Theoretically, attitudes are based on behavioural beliefs, subjective norm on normative beliefs and perceived behavioural control on control beliefs. However, Ajzen and Driver (1991) state that these propositions are subject to empirical test. Where the indirect measures correlate highly with the direct measures only then can they substitute as measures of the three constructs. However, empirical evidence suggests that this may not necessarily be the case with correlations often of only a moderate magnitude (Ajzen & Driver 1991; Gagne & Godin 2000). Ajzen (1991a) himself suggests that this moderate level of correlation is insufficient and considers two explanations. First, Ajzen (1991a) explains that the poor correlation may be due to the level of concentration required to respond to direct and indirect statements. Where direct statements are the result of a relatively automatic response, the indirect statements require more careful deliberation. Second, Ajzen (1991a) suggests that the expectancy-value theory may be insufficient to describe the formation of the constructs attitude, subjective norm and perceived behavioural control. This has led many researchers to question whether the expectancy-value theory is necessary to derive the indirect measures of attitude, subjective norm and perceived behavioural control.

To test this, Gagne and Godin (2000) reviewed 16 studies that used both direct and indirect items, and computed spearman correlation coefficients between i) the direct and indirect measures of the three constructs and ii) the direct measure and just one arm of the expectancy-value theory (i.e., ∑bs ∑ns ∑cp, respectively) for indirect measures. For the construct attitude, Gagne and Godin (2000) found that the correlation coefficients between the direct measure of attitude and ∑bs were often similar or better (in 8 out of 12 studies, 4 of the 16 studies were not used for this construct) than were the correlation coefficients between the direct measure of attitude and ∑(bs x oe). This is in agreement with earlier research by Hom and Hulin (1981) and Nakanishi and Bettman (1974). For subjective norm, Gagne and Godin (2000) found that the correlations between the direct measure of subjective norm and ∑ (ns x mc) were supressed. This is consistent with the findings of Budd et al. (1984), Hom and Hulin (1981), Ajzen and Fishbein (1969) and Ajzen and Driver (1991) and may be due to the issues of social desirability bias mentioned previously. Finally, for perceived behavioural control, Gagne and Godin (2000) found that the correlation coefficients between the direct measure of perceived behavioural control and ∑cp were similar or better than were the correlation coefficients between the direct measure of perceived behavioural control and ∑(cs x cp).

These findings suggest that ‘oe’, ‘mc’ and ‘cs’ do not add to the predictive power of the indirect measures of the constructs. Therefore, it is possible that they may be omitted form the framework, offering a number of advantages including: fewer statements in the questionnaire, consequently reducing the respondent’s time, and the potential for fatigue and boredom. Ultimately, this may result in obtaining more valid information from responders.

Another limitation of the indirect statements is that certain statements have been reported as confusing or difficult for respondents to comprehend. For example, during interviews to pilot a questionnaire, de Leeuw et al. (2015) found that respondents experienced difficulty comprehending the construct outcome evaluation. It is possible that statements such as 'improving animal welfare is good/bad' appears odd to the respondent. In this case, de Leeuw et al. (2015), decided to remove this construct from the questionnaire. In a 'think aloud' study, French et al. (2007) found that respondents required more information to successfully respond to several of the indirect statements. For example, for the normative belief statement 'My partner would want me to be more physically active in the next 12 months', one respondent replied, 'I'm not really sure because I think it would depend what I wanted to do and how much it encroached in what he wanted to do and our time together'. Further, in these cases, some respondents even questioned how sensible the statements were.

French et al. (2007) and Darker and French (2009) found that respondents had particular issue with the normative belief and motivation to comply statements, which, similarly to the direct measure of subjective norm, may be due to social desirability bias. French et al. (2007) suggests that this may be resolved by having the respondent address the motivation to comply statements first, followed by the normative belief statements. The rationale being that this may allow respondents to indicate the level of social influence they feel first and therefore will not need to do so again.

### *Direct and indirect measures*

Using both direct and indirect measures allows all of the objectives described individually for direct and indirect items to be achieved. Additional objectives are to: i) identify the specific beliefs that contribute most to the direct measures of attitude, subjective norm and perceived behavioural control; and to ii) validate the indirect measures of attitude, subjective norm and perceived behavioural control by correlating each with the direct measure of the corresponding construct.

While all of the strengths and limitations discussed independently for direct and indirect measures apply, an additional limitation of using both direct and indirect measures together is the number of statements included in the questionnaire. While direct statements will contribute 12-24 statements, the total number is dependent on the number of salient beliefs identified and used for formulating the indirect statements. The consequences of this increased questionnaire size include: increased time to complete the questionnaire, issues with repetitiveness, boredom and responder fatigue, potentially culminating in a reduced response rate or missing responses from completed questionnaires. However, as discussed, the constructs ‘oe’, ‘mc’ and ‘cs’ may be omitted form the framework, which would significantly reduce the number of items in the questionnaire.

### 2.5.5. Summary

The TPB proposes three psychological constructs, attitude, subjective norm and perceived behavioural control that collectively predict an individual’s intentions to perform a given behaviour. These constructs are antecedent to the construct intention, the most proximate predictor of actual behaviour. At a deeper level, the TPB examines the salient beliefs of the target population to understand why they hold the attitudes, subjective norms and perceived behavioural control that they do.

The constructs of the TPB are measured via responses obtained from a number of statements in a questionnaire. Three approaches are proposed for measuring the constructs, these are: i) direct measures, ii) indirect measures, or, iii) a combination of direct and indirect measures. Each approach has advantages and limitations. Briefly, while the direct approach has the potential to be a short questionnaire, it is limited to prediction of intentions and behaviour. Conversely, while the indirect approach involves a two-step process and has the potential to be a longer questionnaire, these measures allow for an in-depth investigation of why an individual may choose to engage (or not engage) in a particular behaviour. Using both direct and indirect measures offers an opportunity to validate the indirect measures of the constructs. However, using both measures will inevitably increase the number of items included in the questionnaire.

Using indirect measures only is based on the assumption that the direct and indirect measures of a given construct are highly correlated. However, empirical evidence has demonstrated correlations are often only of a moderate magnitude. A number of studies have demonstrated that correlations using just one arm of the expectancy value theory (i.e. ‘bs’, ‘ns’, ‘cp’) were similar or better than were the correlations using the full expectancy value theory. These findings suggest that ‘oe’, ‘mc’ and ‘cs’ do not add to the predictive power of the indirect measures of the constructs. Therefore, it is possible that they may be omitted form the framework. This has the advantage of reducing the number of statements included in the questionnaire.

# 3. Chapter 3: A systematic review of tests for the detection and diagnosis of foot lesions causing lameness in dairy cows

## 3.1. Introduction

Dairy cows frequently succumb to foot lesions as a consequence of host, agent, environment and management interactions. Foot lesions are often painful, typically manifesting in lameness, impacting dairy cow ability to perform normal behaviours and therefore compromise welfare (Callaghan et al. 2003; Whay et al. 2003). In addition, the economic impacts are also substantial as lame dairy cows produce less milk, have poor reproductive performance (Reader et al. 2011) and are often culled prematurely (Booth et al. 2004; Bicalho et al. 2009). In addition to these productivity losses, treatment of individual cases can be costly, ranging from $USD120 to £519 (Kossaibati & Esslemont 1997; Willshire & Bell 2009; Cha et al. 2010). Therefore, the prompt detection and correct diagnosis of foot lesions is important to minimise the associated welfare and economic implications.

The process of diagnosing the type of lesion, from initial detection through to final diagnosis, is an important task and often begins with observation of a lame cow by the dairy farmer. The literature suggests that dairy farmer detection of lameness is relatively poor (Wells et al. 1993; Leach et al. 2010; Šárová et al. 2011). However, there is little evidence available to determine dairy farmer ability to correctly diagnose the type of foot lesion. To aid the dairy farmer in the detection and diagnosis of foot lesions, a number of tests have been investigated in the literature. There is a need to assess the efficacy of these tests to be able to recommend those with high level of accuracy that can be implemented on the farm.

The objectives of this systematic review are to:

1. Identify tests that have been investigated for the detection and diagnosis of foot lesions causing lameness in dairy cows.
2. Report the sensitivity and specificity of the identified tests.
3. Compare the accuracy (sensitivity and specificity) of the tests.
4. Determine which tests can be recommended for implementation on the farm based on test accuracy and practicality for use by dairy farmers.

With these objectives, the systematic review aims to answer the following research questions:

1. What tests have been investigated for the detection and diagnosis of foot lesions in dairy cows?
2. What is the sensitivity and specificity of each test?
3. Which tests are the most accurate?
4. Which, if any of the tests can be recommended for implementation on the farm?

This chapter consists of three sections. The first section provides background information on systematic reviews. This expands to introduce systematic reviews of diagnostic test performance, where important concepts and terminology relevant to the proposed systematic review are introduced. The second section provides a structured approach to the proposed systematic review, detailing question development, study selection criteria, and the assessment of methodological quality. The final section presents the systematic review of tests for the detection and diagnosis of foot lesions causing lameness in dairy cows.

## 3.2. The systematic review – outline and methodologies

### 3.2.1. A general introduction to the systematic review

Systematic reviews are considered as primary research that aim to provide an objective summary of the literature using a pre-defined series of steps (Baker & Weeks 2014; O'Connor & Sargeant 2014b). This differs from a traditional narrative review that lacks an explicit methodology, leading to a subjective review of the literature that may be prone to systematic bias (Garg et al. 2008).

The first step of a systematic review is critical and involves the development of a specific research question; failing to do so may increase the probability of bias (Higgins & Green 2011). Although a systematic review may seek to answer more than one research question, the primary question should be based on a specific parameter of interest (e.g. prevalence, incidence, or effect size) as opposed to developing a list of items or providing a summary of the literature (Sargeant & O'Connor 2014). Systematic review research questions can be classified into four types based on the objectives of the study. These are: intervention, aetiology, disease burden, and diagnostic accuracy (Schmidt & Factor 2013; O'Connor & Sargeant 2014b). Each question type contains a number of components, which are summarised by an acronym (Table 3-1).

Table 3-1: The four types of systematic review research questions, with components summarised by an acronym.

| Study objective | Acronym | Definition of components included in the research question |
|---|---|---|
| Intervention | PICO | P=Population<br>I=Intervention<br>C=Comparator<br>O=Outcome |
| Aetiology | PECO | P=Population<br>E=Exposure<br>C=Comparator<br>O=Outcome. |
| Disease burden | PO | P=Population<br>O=Outcome |
| Diagnostic accuracy | PIT | P=Population<br>I=Index test<br>T=Target condition or disease |

After establishing an appropriate research question, the steps involved in a systematic review are: i) conducting an exhaustive literature search; ii) screening and study selection (where only those studies that adhere to a series of pre-defined selection criteria are included); iii) assessing the risk of bias in individual studies; iv) data synthesis, including tabulation of study characteristics; and, v) interpretation of the findings (Higgins & Green 2011). These steps facilitate transparency, replicability and reduce the potential risk of bias (Baker & Weeks 2014). Given the magnitude of work required for a systematic review, and to reduce the potential for bias, typically, a minimum of two reviewers are involved in each step (Baker & Weeks 2014).

### 3.2.2. The systematic review in human and veterinary medicine

Evidence-Based Medicine (EBM) aims to augment medical decision making by reviewing the current available evidence from appropriately designed and well conducted research studies (Akobeng 2005). EBM has gained increasing popularity over the past decade as the desired approach for decision making in human medicine (Akobeng 2005). The systematic review is one way to provide medical practitioners with a comprehensive summary of the current knowledge on a topic in a single document. Therefore, systematic reviews have been regularly conducted in human medicine to provide practitioners with the best available information (Page et al. 2016).

Systematic reviews in human medicine are supported by published guidelines such as the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement

(Moher et al. 2009), which is highly advocated by journals; and, a number of well-established scientific collaborations such as the Cochrane Collaboration. There are no such guidelines available for the conduct of a systematic review in veterinary medicine. However, the value of the systematic review in veterinary medicine has recently become recognised (O'Connor & Sargeant 2014a) leading to the establishment of a number of collaborations in different countries such as: VetSRev (http://webapps.nottingham.ac.uk/refbase/), an online freely-accessible database of systematic reviews in veterinary medicine, produced by the Centre for Evidence-based Veterinary Medicine (CEVM) at the University of Nottingham in the United Kingdom; EBVM (Evidence-based Veterinary Medicine) as part of the Royal College of Veterinary Surgeons (RCVS) in the United Kingdom (http://knowledge.rcvs.org.uk); and, Systematic Review Centre for Laboratory Animal Experimentation (www.syrcle.nl) in the Netherlands. In addition, since 2014, the Journal of Animal Health Research Reviews (AHRR) has offered to register systematic review protocols for animal health, animal welfare, and food safety topics (O'Connor & Sargeant 2014a).

### 3.2.3. Systematic reviews of diagnostic test accuracy

Systematic reviews of diagnostic test accuracy (DTA) are a special category of systematic review where the accuracy of a diagnostic test is evaluated. In this context the test under investigation is referred to as the 'index test', and accuracy refers to the ability of the test to discriminate between individuals with and without the condition of interest (Manakraker 2010; Mallett et al. 2012). To determine the accuracy of the index test, it is typically measured against a gold standard or reference test that reflects the 'truth' (i.e., whether or not the patient or animal really has the disease or condition being assessed) (Deeks 2001). For the purpose of this review, the term 'reference test' will be used rather than gold standard. Ideally the reference test is the best available method for establishing the presence or absence of the target condition. The reference tests used in each of the included studies will be critically appraised to judge their quality as 'the best available' method.

When the accuracy of a test is being evaluated there are four possible test outcomes: i) true positive (TP), subjects that have the condition of interest and test positive; ii) false positive, (FP), subjects that do not have the condition of interest and test positive; iii) true negative (TN), subjects that do not have the condition of interest and test negative; and iv) false negative (FN), subjects that do have the condition of interest and test negative (Mallett et al. 2012; Eusebi 2013). These parameters are commonly displayed in a 2 x 2 contingency table (Table 3-2). From this, test performance can be quantified by pairs of measures such as sensitivity (Se) and specificity (Sp), positive and negative predictive values (PPV, NPV), and positive and negative likelihood ratios (LR+, LR-) (Table 3-3). These measures are summarised in Table 3-4 along with their strengths and limitations.

Systematic reviews of DTA follow a similar methodology to the more established systematic review of intervention studies (Bossuyt 2008). However, studies of DTA require unique criteria for question design, inclusion criteria and quality assessment, which are outlined in the Cochrane Collaboration guidelines for systematic reviews of DTA (Higgins & Green 2011). This systematic review follows those guidelines.

Table 3-2: Contingency table of test outcomes, where: TP: true positive, FP: false positive, TN: true negative, FP: false negative, P: number of animals with condition of interest, S: number of all animals included in analysis.

| | | Reference test | | |
|---|---|---|---|---|
| | | Positive | Negative | |
| Index test | Positive | TP | FP | |
| | Negative | FN | TN | |
| | | P | S-P | S |

Table 3-3: Calculations for test outcomes and measures of test performance.

| Test outcome | Abbreviation | Equation |
|---|---|---|
| True positive | TP | TP = Se x P |
| False positive | FP | FP = (S – P) – TN |
| True negative | TN | TN = Sp x (S – P) |
| False negative | FN | FN = P – TP |
| Sensitivity | Se | Se = TP/P |
| Specificity | Sp | Sp = TN/S-P |
| Positive predictive value | PPV | PPV = TP/(TP + FP) |
| Negative predictive value | NPV | NPV = TN/(FN + TN) |
| Positive likelihood ratio | LR+ | LR+ = Se/(1-Sp) |
| Negative likelihood ratio | LR- | LR- = (1-Se)/Sp |

P: number of animals with condition of interest, S: number of all animals included in analysis

Table 3-4: Definitions of the various measures of test performance, including their strengths and limitations.

| Measure | Definition | Strengths of each pair of measures | Limitations of each measurement pair |
|---|---|---|---|
| Sensitivity (Se) | Probability of a positive test result among animals having the condition of interest. | Not dependent on disease prevalence, therefore results from one study population can be extrapolated to another with a different disease prevalence. | Dependent on study population characteristics and setting, therefore in a different context, Se and Sp are likely to change. Dependent on the spectrum of disease. Se and Sp are inversely proportional, i.e. as one increases, the other decreases. |
| Specificity (Sp) | Probability of a negative test result among animals without the condition of interest. | | |
| Positive predictive value (PPV) | Probability that given a positive test result the animal does have the disease. | Provide an indication of how accurate the test is at predicting the true disease status of the animal | Dependent on disease prevalence, therefore cannot be extrapolated from one study population to another with a different disease prevalence. Dependent on the spectrum of disease. |
| Negative predictive value (NPV) | Probability that given a negative test result, the animal does not have the disease. | | |
| Positive likelihood ratio (LR+) | Ratio of the probability of a positive test result among animals with the disease to the probability of a positive test result among animals without the disease. | Not dependent on disease prevalence, therefore results from one study population can be extrapolated to another with a different disease prevalence. | Dependent on the spectrum of disease. |
| Negative likelihood ratio (LR-) | Ratio of the probability of a negative test result among animals without the disease to the probability of a negative test result among animals with the disease. | | |

### 3.2.4. The definition of a test

In a veterinary clinic or other medical setting, the term “test” is often associated with laboratory procedures of a sample in anticipation of a diagnosis (e.g., blood or other samples are taken from the animal or human patient and subsequently sent to a laboratory for a number of laboratory procedures). However, a test may be defined as any method or procedure that has facilitated the diagnostic process, resulting in a different post-test probability of a particular diagnosis from the pre-test probability (Greiner & Gardener 2000). Therefore, the definition of a test encompasses all investigations intended to detect and diagnose abnormal health (O'Connor & Evans 2007). In this context, history taking and clinical examination of animal or human patients by a veterinarian or medical practitioner are considered as tests (O'Connor & Evans 2007; White et al. 2011).

A test may be used for one of four major functions: screening, monitoring, diagnosing, or staging. The majority of these terminologies have been defined for human medicine. However, there can be important differences when these terminologies are applied to veterinary medicine. For example, a monitoring test in the context of human medicine is the observation of a patient who is already known to have or is suspected of having the condition of interest (O'Connor & Evans 2007; National Institute for Health and Clinical Excellence 2011). While this may occasionally apply to veterinary medicine, a monitoring test, particularly at the herd level, is more typical in situations where the animals are not known to have the condition of interest. In this context monitoring is distinguishable from screening in that it is a longitudinal measure as opposed to a cross-sectional measure. Table 3-5 provides definitions and examples from veterinary medicine for the four major functions of a test: screening, monitoring, diagnosing, and staging.

### 3.2.5. The diagnostic process

The diagnostic process may be considered as a sequence of steps. This typically begins with the detection of abnormal health, in the form of one or more signs, via casual observation or from utilising screening or monitoring tests. Upon detection of abnormal health, the goal of the diagnostic process is to determine which specific disease or condition explains the presenting signs (i.e., establishing a diagnosis). Following a diagnosis, further stages of the diagnostic process may involve staging or prognosis, prior to ultimately prescribing a treatment. However, because many symptoms of disease are non-specific, diagnosis is often challenging. Therefore, in a process of hypothetico-deductive reasoning, all possible diagnoses are identified (differential diagnosis), and tests are used to confirm or exclude each possible diagnosis (Elstein et al. 1978).

Table 3-5: Definitions and examples of each test function and their application at the individual animal level and herd level.

| | Individual animal level | | Herd level | |
|---|---|---|---|---|
| Test category | Definition | Example | Definition | Example |
| Screening | Investigation of the presence of a condition in an animal currently without signs of the condition in question. | Collecting faeces for culture from an individual animal that has shown a positive serological test (ELISA) for Johne's Disease in a herd screening program. | Investigation of the presence of a condition at the herd level. The aim is to detect those with signs of the specific condition. | Observing dairy cows fortnightly as they enter the milking parlour, assigning each a lameness score (e.g., 0-5 scale where: 0=not lame, 5=severely lame). |
| Monitoring | Observing an animal known to have or suspected of having the condition of interest, over time to detect changes in their health. The intention is to detect changes with the aim of allowing timely intervention to prevent further deterioration or appearance of signs. | A cow presenting with mild lameness may be monitored daily by the dairy farmer to see if the lameness is temporary or more chronic. | Observing the herd over time to detect changes in their health. May apply when the herd is not known to have the condition of interest. The intention is to detect changes with the aim of allowing timely intervention to prevent further deterioration or appearance of signs. | Sampling milk to determine the somatic cell count (SCC) to test for mastitis (Bortolami et al. 2015). |
| Diagnosis | The process of distinguishing one disease, condition or syndrome from another. It is performed for animals presenting with clinical signs that may be indicative of a specific disease. | An individual cow presenting with diarrhoea may be tested for salmonella by collection of faeces to submit for culture. | The process of distinguishing one disease, condition or syndrome from another at the herd level. Typically, it is performed for a sub-set of the herd to determine the disease as present or absent (Donald et al. 1994). | Diagnosis of bovine viral diarrhoea requires the veterinarian to submit serum or nasal swabs from a subset of the herd to the laboratory. Presence of virus, in conjunction with clinical signs, confirms diagnosis. |
| Staging | Determination of the severity or how advanced the diagnosed disease, condition or syndrome is. | Diagnosis of digital dermatitis in dairy cows involves allocating a stage of 0 to 5 for the lesion using the 5-point M-stages M0-M5 scale (Relun et al. 2011). | Not applicable. | Not applicable. |

### 3.2.6. Defining detection and diagnosis

The terms detection and diagnosis are commonly used in human and veterinary medicine. While these are distinct terms, they are often used interchangeably in the literature. For the purpose of this review the following definitions will be used: detection, the act of discovering clinical signs of a disorder or disease (i.e., the initial discovery of signs of disease in an individual previously considered healthy); and, diagnosis, the distinguishing of one disease or condition from another (US National Library of Medicine 2017a).

## 3.3. A structured approach for the proposed systematic review

### 3.3.1. Development of the primary research question and study selection criteria

In order to formulate an appropriate research question for a systematic review of diagnostic test accuracy, the PIT approach is recommended (O'Connor & Sargeant 2014b). Using this approach, the components i) population, ii) index test and iii) target condition should be included in the research question (O'Connor & Sargeant 2014b). Further, it was considered important to include the measures of test accuracy examined. Application of these components to the proposed systematic review is as follows:

i) Population: lactating dairy cows.

ii) Index test: all available methods (technologies and observations) used for detection and diagnosis. For the purpose of this systematic review the term “test” will be used for “index test” throughout this document.

iii) Target condition: foot lesions causing lameness, where the term “foot lesion” includes all lesions of the cow foot and hoof. For the purpose of this systematic review, studies with the objective of detecting lameness will also be included as the clinical presentation of lameness is typically the first indication of the presence of a foot lesion.

iv) Measures of test accuracy: sensitivity and specificity.

The resulting question is, “What are the sensitivities and specificities of tests used for the detection and diagnosis of foot lesions causing lameness in dairy cows”?

Selection criteria for inclusion of studies in the systematic review were also developed using the above approach with two additional components: reference test and study design. Descriptions of how these criteria were applied to the aforementioned research question are presented in Table 3-6.

Table 3-6: Selection criteria used for the inclusion of studies in the systematic review: A systematic review of methods for the detection and diagnosis of foot lesions causing lameness in dairy cows.

| Criteria | Rationale |
|---|---|
| Population | The population of interest.<br>Primiparous and multiparous lactating dairy cows. Heifers were excluded because lesions primarily affect dairy cows approaching parturition or at parity one or greater. Further, lactating cows are also observed at least twice a day whereas heifers are not. |
| Index test | The tests considered for evaluation.<br>For the purposes of this systematic review all methods (technologies and observations) used for screening, monitoring, detection, diagnosis, or staging of foot lesions or lameness in dairy cows were considered. |
| Target condition | The condition/s of interest.<br>i) Foot lesions, including all potential lesions of the foot and hoof structures, and;<br>ii) The clinical sign lameness. |
| Reference test | The comparator test.<br>The reference test was expected to vary for each study and target condition, therefore, no reference test was determined *a priori.* |
| Measures of test accuracy | How test accuracy will be measured.<br>The priority test accuracy measures in this study were sensitivity and specificity. |
| Study design | Included study designs.<br>Only prospective observational study designs were included in this review. |

### 3.3.2. Assessment of methodological quality

Systematic reviews of DTA perform an ‘assessment of methodological quality’, where aspects of both internal and external validity are considered (Reitsma et al. 2009). The assessment of methodological quality has two major components: i) risk of bias, and ii) concerns of applicability (Reitsma et al. 2009; Whiting et al. 2011). Bias is a systematic error or deviation from the truth and can arise through problems in the design or execution of the study, ultimately compromising internal and external validity (Dohoo et al. 2009). There are several sources of bias to consider in systematic reviews of DTA; these are described in Table 3-7. Concerns of applicability consider the extent that the execution of a study is relevant to the research question proposed by the systematic review (Whiting et al. 2011). For example, are there concerns that the included animals, the conduct of the index test, or the target condition as defined by the reference test do not match the review question?

Table 3-7: The major types of bias that can occur in studies of diagnostic test accuracy, adapted and modified from Lawrence et al. (2011).

| Type of bias | When does it occur? | How does it impact test performance |
|---|---|---|
| Animals | | |
| Selection bias | When eligible animals are not selected randomly. | Typically results in an over estimation of test accuracy. |
| Spectrum bias | When included animals do not represent a wide spectrum of severity for the target condition. | The sensitivity of a test will often vary according to the severity of disease; thus, the accuracy of a test would be expected to be superior in a study population where the majority of animals are in the advanced stage of the disease. |
| Index test | | |
| Test review bias | When the index test results are interpreted with knowledge of the reference test results. | Typically results in an overestimation of test accuracy. |
| Threshold bias | When the threshold is not pre-determined. | The selection of a threshold value that maximises the sensitivity and specificity of the test may lead to over optimistic measures of test accuracy. |
| Reference test | | |
| Diagnostic review bias | When the reference test results are interpreted with knowledge of index test results. | Typically results in an overestimation of test accuracy. |
| Threshold bias | When the threshold is not pre-determined. | The selection of a threshold value that maximises the sensitivity and specificity of the test may lead to overoptimistic measures of test accuracy. |
| Misclassification or reference test bias | When the reference test does not correctly classify animals with the target disease/condition. | Underestimation (when different aspects are measured) or overestimation (when similar aspects are measured). |
| Partial verification | When a number of animals who have received the index test do not receive the reference test. | Typically results in an overestimation of sensitivity. |
| Differential verification | When a number of animals receive an alternate reference test, especially when this selection depends on the index test result. | Typically results in an overestimation of test accuracy. |
| Incorporation bias | When the index test forms part of the reference test. | Typically results in an overestimation of test accuracy. |
| Recovery or disease progression bias | When there is a delay between the performance of index and reference tests or the animal has been treated between tests. | Under or overestimation of test accuracy, depending on the change in the animal's condition. |

The QUADAS-2 tool (Whiting et al. 2003; Whiting et al. 2011) has been developed especially for the quality assessment of DTA studies in human medicine and consists of four domains: i) patient selection, ii) index test, iii) reference test, and iv) flow and timing. Each domain is assessed for risk of bias and uses signalling questions to judge the risk as high, low or unknown. The first three domains are also assessed in terms of applicability (Whiting et al. 2011). The QUADAS-2 tool is a dynamic tool, allowing reviewers to add or omit signalling questions as appropriate (Reitsma et al. 2009). There are currently no specific guidelines available for the assessment of methodological quality in veterinary studies. However, given the flexible nature of the QUADAS-2 tool, it can be modified to adapt to animal populations. The sources of bias and concerns of applicability that are considered pertinent to this systematic review are described in Table 3-8.

Table 3-8: Domain descriptions and signalling questions to determine sources of bias and concerns of applicability for each domain relevant to the proposed systematic review.

| Domain | Domain description | Signalling questions for sources of bias | Signalling questions for concerns regarding applicability |
|---|---|---|---|
| Animal selection | Describe the methods used for the selection of animals used in the study. | Was a random sample of animals used in the study?<br>Did the study avoid inappropriate exclusions?<br>Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Are there concerns that the included animals do not match the review question? |
| Index test | Describe the index test and how it was conducted and interpreted. | Were the index test results interpreted without knowledge of the results of the reference test?<br>If a threshold was used, was it pre-specified? Did the study provide a clear definition of what was considered to be a positive result? | Are there concerns that the conduct or interpretation of the index test differ from the review question? |
| Reference test | Describe the reference test and how it was conducted and interpreted. | Is the reference test likely to correctly classify the target condition?<br>Were the reference test results interpreted without knowledge of the results of the index test?<br>Did animals receive the same reference standard irrespective of the index test result?<br>Was the reference standard independent of the index test (i.e., the index test did not form part of the reference standard)?<br>Did the study provide a clear definition of what was considered to be a positive result? | Are there concerns that the target condition as defined by the reference test does not match the review question? |
| Flow and timing | Record any animals that did not receive the index test and/or reference test; record any animals that were excluded from analysis; describe the time interval between tests. | Is the time period between reference and index test short enough to ensure the target condition did not change between the two tests?<br>Did all animals receive the same reference test?<br>Were withdrawals explained?<br>Was treatment withheld until both the index test and reference standard were performed? | Not applicable |

## 3.4. A systematic review of tests for the detection and diagnosis of foot lesions causing lameness in dairy cows

### 3.4.1. Materials and methods

*Protocol*

This systematic review was conducted using the guidelines of the Cochrane Collaborations handbook for systematic reviews of diagnostic test accuracy (Higgins & Green 2011) and the PRISMA statement (Moher et al. 2009). A pre-defined protocol was established using these guidelines before conducting the systematic review (Appendix 1).

*Inclusion criteria*

The following inclusion criteria were applied to papers:

- Peer-reviewed papers written in English.
- A description of a test used for the detection of lameness or the detection or diagnosis of foot lesions in dairy cows was provided.
- A reference test was used.
- Primiparous and/or multiparous lactating dairy cows were used.
- Sensitivity and specificity data were provided.

*Literature search*

The search engines used to identify papers were: i) PubMed, using medical subject headings (MeSH) (1951 - February 2015); ii) Web of Science, Core Collection, advanced search (1990 – February 2015); and iii) Agricola, advanced search in both the Article Citation Database and National Agricultural Library (NAL) catalogue (1970 - February 2015). Database specific search terms were created to ensure the database search contained literature relevant to the topic. Full searches applied to each database are provided in Appendix 2. In addition, the references of the included papers were checked for relevant papers.

*Paper selection*

Titles and abstracts of all papers identified by the literature search were examined against the pre-defined eligibility criteria by the primary reviewer. Where an article appeared to meet the inclusion criteria, the full text was obtained and then subjected to a second phase of screening to ensure compliance with the inclusion criteria. Where there was uncertainty about the eligibility of a particular paper, the article was discussed with the second reviewer.

### *Data extraction*

A standardised data collection form was developed by the primary reviewer (Appendix 3) This form was adapted from the Standards for Reporting of Diagnostic Accuracy (STARD) statement checklist of items that should be included in studies of diagnostic test performance (Bossuyt et al. 2015). The form was pilot tested using a sample of the studies to be reviewed. From each included study, the primary review extracted information regarding author and publication date, publication type (e.g., journal article, short communication), setting and methods (e.g., country, context, study design), population (e.g., eligibility/selection criteria, number of cows, health status of included cows, number of farms, withdrawals, mean parity, average days in milk (DIM), daily or yearly milk yield, feed type, housing and milking system), details of the index test (method) investigated (e.g., manufacturer, operator, settings), type of test (e.g., screening, monitoring), details of reference test (e.g., operator, settings, definition of positive case), unit of analysis (e.g., cow, hind limb), measures of test accuracy (i.e., sensitivity and specificity), data for 2 x 2 tables (TP, TN, FP, FN), prevalence, and main conclusions. Where there were missing data, the corresponding author/s were contacted to obtain further information. Where necessary and where adequate information was provided, the values for TP, TN, FP and FN were calculated as detailed in Table 3-2.

A number of papers included the investigation of more than one test (i.e., more than one method). In this case, the paper was regarded as having two or more unique studies and a separate data collection form was used (i.e., one form per test). The included studies may have assessed the test under a variety of conditions (e.g., different temperature thresholds). Each assessment of a test with a reference test within a study was referred to as a comparison.

### *Assessment of methodological quality*

The methodological quality of each study was assessed by the primary reviewer using signalling questions and guidelines of the QUADAS-2 tool for risk of bias and concerns of applicability as detailed in Appendix 4. Risk of bias and concerns of applicability were determined as detailed in Table 3-9. Where insufficient detail was reported in a study the corresponding author was contacted for further clarification. If no further information was provided the risk was reported as ‘unclear’. Where there was uncertainty about the methodological quality, this was discussed and resolved with the second reviewer.

Table 3-9: Assessing methodological quality of included trials - risk of bias and concerns of applicability.

| | Risk of bias | | | Concerns of applicability | | |
|---|---|---|---|---|---|---|
| Domain | Low | High[1] | Unclear[1] | Low | High[1] | Unclear[1] |
| Animal selection | If all signaling questions answered 'yes'. | If 'no' was reported for at least one signaling question. | If 'unclear' was reported for at least one signalling question. | If selected animals matched the review question, which reflects the way the test will be used in practice. | If selected animals differed from those in the review question and do not represent those for which the test will be used in practice. | If there was insufficient information on included subjects. |
| Test | If all signaling questions answered 'yes'. | If 'no' was reported for at least one signaling question. | If 'unclear' was reported for at least one signalling question. | If the test was performed as described in the methodology. | If the test differed from those specified in the methodology. | If there was insufficient information available. |
| Reference test | If all signaling questions answered 'yes'. | If 'no' was reported for at least one signaling question. | If 'unclear' was reported for at least one signalling question. | If the reference test was performed as described in the methodology. | If the reference test differed from those specified in the methodology. | If there was insufficient information available. |
| Flow and timing | If all signaling questions answered 'yes'. | If 'no' was reported for at least one signaling question. | If 'unclear' was reported for at least one signalling question. | NA | NA | NA |

[1]If both 'no' and 'unclear' are reported within the same domain, overall the domain will be reported as 'high'.

## 3.5. Results

### 3.5.1. Search results

A total of 2,137 papers were identified through electronic databases. Following initial screening by title and abstract and after the removal of duplicates, 73 papers were found to be eligible for full text screening. No additional papers were found after checking the references of these papers. After full text screening, a total of 41 papers did not meet the inclusion criteria and were excluded. Full details of excluded papers and their primary reason for exclusion are presented in Appendix 5. Of the remaining papers (n = 26), a number of these used mathematical modeling to detect lameness (n = 13) or foot lesions (n = 1). After careful consideration, although these papers were consistent with the inclusion criteria, it was decided to exclude them as their methodologies were beyond the scope of this review, compromising a thorough methodological quality assessment. Full details of these papers are presented in Appendix 6. A total of 12 papers with 20 studies (three papers explored more than one test) met the inclusion criteria for the systematic review. The search results are presented in Figure 3-1.

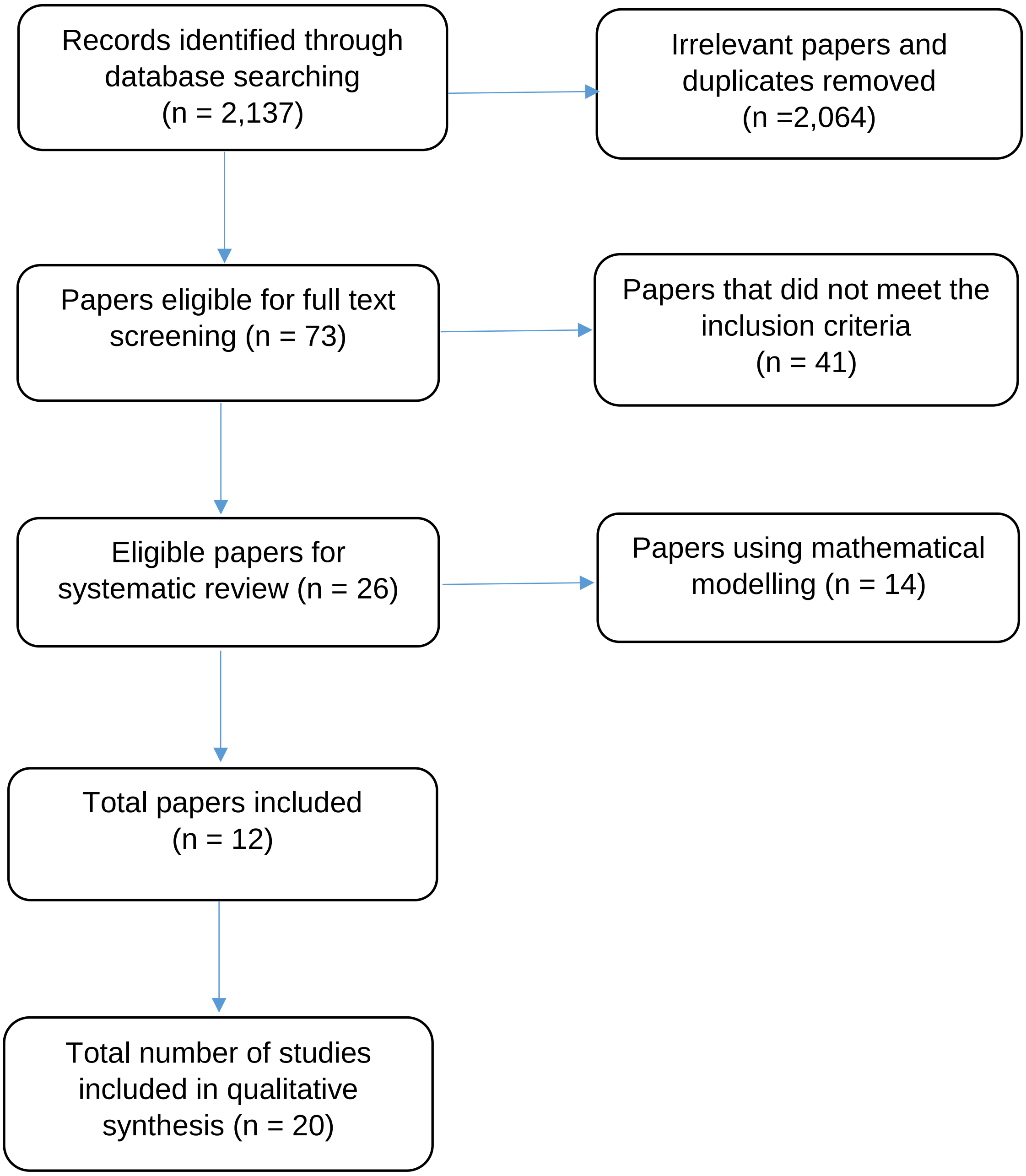


Figure 3-1: The PRISMA four-phase flow diagram demonstrating the literature search.

### 3.5.2. Study characteristics

#### *Tests identified*

The included studies were grouped according to the objective of the test under investigation, resulting in the following groups:

- Tests used to detect lameness:
    i. Observation of lameness indicators (Leach et al. 2009).
    ii. Observation of an arched back (Thomsen 2009).
- Tests used to detect foot lesions:
    i. Infra-red thermography (Alsaaod & Buscher 2012; Main et al. 2012; Stokes et al. 2012a).
    ii. Locomotion scoring using a five-point scale (Bicalho et al. 2007a).
    iii. Locomotion scoring using a force plate system (Bicalho et al. 2007a).
- Tests used to detect sole ulcer. These studies were all from one paper (Chapinal et al. 2009) and investigated the observation of gait characteristics. These were:
    i. Abduction/adduction
    ii. Back arch
    iii. Head bob
    iv. Tracking up
    v. Joint flexion
    vi. Asymmetric steps
    vii. Reluctance to bear weight
- Tests used to detect and stage digital dermatitis:
    i. Infra-red thermography (Alsaaod et al. 2014).
    ii. Visual inspection in a milking parlour with swivelling mirror and powerful headlamp (Relun et al. 2011).
    iii. Visual inspection in a milking parlour (Rodriguez-Lainz et al. 1998; Thomsen et al. 2008a; Stokes et al. 2012b).
    iv. Visual inspection in a milking parlour using a borescope (an optical device consisting of a tube with an eyepiece on one end, and an objective lens on the other linked together by a relay optical system) (Stokes et al. 2012b).

Full details of these different tests, including (where applicable) the operator/s, skill level of operator/s and level of concordance between operators are detailed in Table 3-10. A description of each test and manufacturer details (where available) are provided in Appendix 7

### *Study design*

Two studies from a single paper identified the study design used; however, no definition of the study design was provided (Table 3-11). The reviewers determined the study design of each study. Using the reviewers definitions, the studies investigating these methods were either cross-sectional, an observational study collecting data from a population at a specific point in time (n = 7); case-control, a study comparing animals with (cases) and without the condition of interest (controls) (n = 3); or prospective observational study design, where all animals were monitored over a period of time (n = 10).

### *Reference tests*

The reference tests used in the studies were observational methods (methods that do not use any technology and are based on observation, skills and experience of operators) and therefore prone to subjectivity (Table 3-12). The studies investigating tests for the detection of lameness used a LCSS, while all other groups (foot lesion detection, sole ulcer detection and digital dermatitis detection) used visual examination of the affected foot. Within each group there was variability in the definition used by the reference test to determine a positive case (including the level of detail provided) and the operator used, including skill level. Four studies failed to report the operator of the reference test and seven studies failed to report the skill level of the operator.

### *Population Characteristics*

The selection criteria for farms and dairy cows used by each study and the spectrum of disease in the selected population were poorly reported (Table 3-13). Further, most studies failed to report basic population parameters (Table 3-14).

Table 3-10: Information for each test identified, including: test function, test measurement (as reported in study), test operator and number of operators, operator skill level and the concordance between operators (applicable where there was more than one operator).

| Author | Country | Test | Test function | Test measurement | Operator of test (no.) | Skill level of operator | Concordance between operators (*k*) |
|---|---|---|---|---|---|---|---|
| **Lameness detection** | | | | | | | |
| Leach et al. (2009) | Austria | Observation of lameness indicators | Screening | Presence of at least two of the following signs: regular shifting of feet, rotation of feet, standing on the edge of a step, resting one foot more than another, uneven weight bearing between feet. | Veterinary surgeon (1) | Experienced in husbandry of tied cows | NA |
| Thomsen (2009) | Denmark | Observation of arched back | Screening | Presence/absence of arched back. | Agricultural technician (1) | Experienced in LCS | NA |
| **Foot lesion detection** | | | | | | | |
| Alsaaod and Buscher (2012) | Germany | Infra-red thermography | Screening | Surface temperature of coronary band and skin. | Not reported | Not reported | Not reported |
| Bicalho et al. (2007a) Study 1 | USA | Force plate system | Screening | Force and duration of steps, providing an automated locomotion score, scale 1-100. | NA | NA | NA |
| Bicalho et al. (2007a) Study 2 | USA | LCS system (scale 1-5) | Screening | 1: normal, 2: presence slightly asymmetrical gait, 3: cow clearly favours one or more limbs, 4: severely lame, 5: extremely lame. | Veterinarian (3) | Trained in LCS | Observers 1 & 2=0.46, 1 & 3=0.45, 2 & 3 =0.48 |
| Main et al. (2012) | UK | Infra-red thermography | Screening | Temperature recorded from the plantar aspect of each hind foot immediately proximal to the heel bulb and distal to the accessory digits. | Not reported | Not reported | Not reported |

| Author | Country | Test | Test function | Test measurement | Operator of test (no.) | Skill level of operator | Concordance between operators (*k*) |
|---|---|---|---|---|---|---|---|
| Stokes et al. (2012a) | UK | Infra-red thermography | Screening | Hoof temperature taken from the plantar aspect of each foot. | Not reported | Not reported | Not reported |
| **Sole ulcer detection** | | | | | | | |
| Chapinal et al. (2009) Study 1 | Canada | Observation of abduction/adduction | Screening | A cow demonstrating abduction/adduction | Experienced observer (1) | Experienced | NA |
| Chapinal et al. (2009) Study 2 | Canada | Observation of back arch | Screening | A cow demonstrating an arched back | Experienced observer (1) | Experienced | NA |
| Chapinal et al. (2009) Study 3 | Canada | Observation of head bob | Screening | A cow demonstrating head bobbing | Experienced observer (1) | Experienced | NA |
| Chapinal et al. (2009) Study 4 | Canada | Observation of tracking up | Screening | A cow demonstrating tracking up | Experienced observer (1) | Experienced | NA |
| Chapinal et al. (2009) Study 5 | Canada | Observation of joint flexion | Screening | A cow demonstrating joint flexion | Experienced observer (1) | Experienced | NA |
| Chapinal et al. (2009) Study 6 | Canada | Observation of asymmetric steps | Screening | A cow demonstrating asymmetric steps | Experienced observer (1) | Experienced | NA |
| Chapinal et al. (2009) Study 7 | Canada | Observation of reluctance to bear weight | Screening | A cow demonstrating reluctance to bear weight on the affected limb/s | Experienced observer (1) | Experienced | NA |
| **Digital dermatitis detection** | | | | | | | |
| Alsaaod et al. (2014) | Switzerland | Infra-red thermography | Screening | Maximal surface temperatures of the coronary band and skin. | Not reported | Not reported | Not reported |
| Relun et al. (2011) | France | Visual inspection in milk parlour with swivelling mirror and powerful headlamp | Screening | Lesions scored using M-stage scoring system: M0: feet with no skin lesions present; M1: early stage lesion present; M2: ulcerative or granulomatous stage with a diameter >2 cm; M3: healing stage lesion has | Corresponding author (1) and veterinarians (4) | The four veterinarians were trained by the corresponding author in the use of the M-5 | 0.51 (overall) |

| Author | Country | Test | Test function | Test measurement | Operator of test (no.) | Skill level of operator | Concordance between operators (*k*) |
|---|---|---|---|---|---|---|---|
| | | | | formed a scab-like material; M4: late chronic stage. | | stages scoring system | |
| Rodriguez-Lainz et al. (1998) | South America | Visual inspection in milk parlour | Screening | Lesions were classified into the three stages: i) early: <2cm, concave or flat, with red granular surfaces; ii) classical: >2cm with red granular areas; and, iii) papillomatous: raised, with predominantly papillary surfaces. | Not reported | Not reported | Not reported |
| Stokes et al. (2012b) Study 1 | UK | Visual inspection in milk parlour | Screening | Stage of infection described by Vink (2006), depth and colour assessed visually according to Laven (1999) and size measured in mm. | Not reported | Not reported | Not reported |
| Stokes et al. (2012b) Study 2 | UK | Visual inspection in milk parlour using borescope | Screening | Stage of infection described by Vink (2006), depth and colour assessed visually according to Laven (1999) and size measured in mm. | Not reported | Not reported | Not reported |
| Thomsen et al. (2008a) | Denmark | Visual inspection in milk parlour | Screening | Lesions scored as follows: 0: no lesion, 1: Hyperaemic area with erect pili, 2: Moist, exudative, and hyperaemic area, with intact epidermis, 3: Exudative area, exposed corium, 4: Exposed corium, 5: Dark brown scab. | Trained observer (1) | Received training from an experienced veterinarian | NA |

LCS: locomotion scoring; *k*: Cohens kappa statistic, a measure of concordance between two or more different operators, NA: Not applicable; M-stage scoring system: A scoring system developed to classify the different stages of digital dermatitis, where "M" stands for Mortellaro (Digital dermatitis is also known as Mortellaro disease).

Table 3-11: Study designs used by each study as reported by the study author and as defined by the reviewers.

| Author | Study design as stated by author | Study design as defined by reviewer |
|---|---|---|
| **Lameness detection** | | |
| Leach et al. (2009) | Not reported | Cross-sectional[1] |
| Thomsen (2009) | Not reported | Cross-sectional |
| **Foot lesion detection** | | |
| Alsaaod and Buscher (2012) | Not reported | Prospective observational[2] |
| Bicalho et al. (2007a) Study 1 | Prospective observational | Prospective observational |
| Bicalho et al. (2007a) Study 2 | Prospective observational | Prospective observational |
| Main et al. (2012) | Not reported | Cross sectional |
| Stokes et al. (2012a) | Not reported | Case-control[3] |
| **Sole ulcer detection** | | |
| Chapinal et al. (2009) Studies 1 to 7 | Not reported | Prospective observational |
| **Digital dermatitis detection** | | |
| Alsaaod et al. (2014) | Not reported | Cross-sectional |
| Relun et al. (2011) | Not reported | Cross-sectional |
| Rodriguez-Lainz et al. (1998) | Not reported | Cross-sectional |
| Stokes et al. (2012b) Studies 1 & 2 | Not reported | Case-control |
| Thomsen et al. (2008a) | Not reported | Cross-sectional |

[1]Cross-sectional study design as defined by reviewers: a type of observational study that collects data from a population at a specific point in time; [2]prospective observational study design as defined by reviewers: where all animals were monitored over a period of time; [3]case-control study design as defined by reviewers: a study that compares animals who have the condition of interest (cases) with animals who do not have the condition of interest (controls).

Table 3-12: Reference test information including definition of a positive case (as reported in the study), operator, number of operators, operator skill level and the concordance between operators (applicable where there was more than one operator).

| Author | Reference test | Definition | Operator (No.) | Skill level | Concordance |
|---|---|---|---|---|---|
| **Lameness detection** | | | | | |
| Leach et al. (2009) | 5-point LCSS (Winckler & Willen 2001b). | 1: Normal gait, 2: uneven gait, 3: limp visible, 4: strong reluctance to bear weight on one limb, 5: does not bear weight on one limb. | Experienced personnel (1) | Experienced in LCS | Not applicable |
| Thomsen (2009) | 5-point LCSS (Thomsen et al. 2008b). | As described by Thomsen et al. (2008b). | Agricultural technician (1) | Experienced in LCS of dairy cows | Not applicable |
| **Foot lesion detection** | | | | | |
| Alsaaod and Buscher (2012) | Visual inspection | Softness of horn tissue, evaluation of pain and smell. | Not reported | Not reported | Not reported |
| Bicalho et al. (2007a) Studies 1 & 2 | Visual inspection | Reaction when digital pressure applied to the lesion or if cow had an obviously painful lesion. PL scored for severity where: 1: mild, and 2: advanced. | Veterinarians (3) | Not reported | Not reported |
| Main et al. (2012) | Visual inspection | Inspection at hoof trimming. | Foot trimmer (1) | Experienced | Not applicable |
| Stokes et al. (2012a) | Visual inspection | Lesions (DD, sole haemorrhage, sole ulcer, white line disease, interdigital growth) were recorded. | Unclear | Unclear | Not reported |
| **Sole ulcer detection** | | | | | |
| Chapinal et al. (2009) Studies 1 to 7 | Visual inspection | Presence, location, severity of sole ulcer (scale 1-8 where: 1: diffuse red or yellow; 2: stronger red; 3: deep, dense red; 4: port coloration; 5: red, raw; 6: ulcer, corium exposed; 7: severe ulcer, major loss of horn; 8: infected ulcer). | Experienced observer (1) | Experienced | Not applicable |
| **Digital dermatitis detection** | | | | | |
| Alsaaod et al. (2014) | Visual inspection | Foot lifted and inspected in a cattle crush. 5-point M-stages scoring system, where: M0: no lesion, M1: early stage DD <2cm diameter, M2: ulcerative stage | Paper authors (2) | Trained in scoring digital dermatitis | Not reported |

| Author | Reference test | Definition | Operator (No.) | Skill level | Concordance |
| --- | --- | --- | --- | --- | --- |
| | | >2cm diameter, M3: healing stage, M4: late chronic stage. | | | |
| Relun et al. (2011) | Visual inspection | Foot lifted and inspected in a cattle crush. 5-point M-stages scoring system. The DD score was formulated by having all 5 observers and an experienced hoof trimmer reach a general consensus (1 trimmer on the first and second farms and 2 on the third and fourth farms). | Paper author (1), veterinarians (4) and hoof trimmer (1 trimmer on the first two farms and 2 on the third and fourth farms). | The four veterinarians were trained by the paper author in the use of the 5-point M0 - M5 scale. | 0.51 (excluding hoof trimmers) |
| Rodriguez-Lainz et al. (1998) | Visual inspection | Foot lifted and inspected in a cattle crush. The following items were recorded: presence of DD lesions (foot affected, location and type), and presence and location of other digital infectious diseases. | Not reported | Not reported | Not reported |
| Stokes et al. (2012b) Studies 1 & 2 | Visual inspection | Foot lifted and inspected in a cattle crush. Lesion descriptors: stage of infection described by Vink (2006), depth and colour assessed according to Laven (1999) and size (greatest diameter) measured in mm. | Not reported | Not reported | Not reported |
| Thomsen et al. (2008a) | Visual inspection | Foot lifted and inspected in a cattle crush. Lesions scored as follows: 0: no lesion, 1: hyperemic area with erect pili, 2: moist, exudative, and hyperemic area, with intact epidermis, 3: exudative area, exposed corium, 4: exposed corium, 5: dark brown scab. | Trained observer (1) | Observer received training for DD scoring | Not applicable |

LCSS: locomotion scoring system; LCS: locomotion scoring; DD: digital dermatitis; M-stage scoring system: a scoring system developed to classify the different stages of digital dermatitis, where "M" stands for Mortellaro (digital dermatitis is also known as Mortellaro disease).

Table 3-13: Selection criteria of population and spectrum of disease for each study.

| Author | No. dairy farms | Dairy farm selection criteria | No. cows | Cow selection criteria | Spectrum of disease in population |
|---|---|---|---|---|---|
| **Lameness detection** | | | | | |
| Leach et al. (2009) | 4 | Not reported | 95 | Not reported | Not reported |
| Thomsen (2009) | 3 | Not reported | 454 | Not reported | Not reported |
| **Foot lesion detection** | | | | | |
| Alsaaod and Buscher (2012) | 1 | Not reported | 24 | Randomly selected | Not reported |
| Bicalho et al. (2007a) Studies 1 & 2 | 1 | Not reported | 518 | Not reported | Not reported |
| Main et al. (2012) | 6 | Not reported | 143 | Dairy cows that were undergoing routine foot trimming. | Not reported |
| Stokes et al. (2012a) | 4 | Herds were endemically infected with digital dermatitis and herdsmen were willing to allow a researcher to examine cows for a period of four months. | 82 | In the milking parlour one cow per row was selected for inspection. | There were two groups of cows: i) cows with no skin lesions on the hind feet (control), and ii) cow with a digital dermatitis lesion on one or both of the hind feet. |
| **Sole ulcer detection** | | | | | |
| Chapinal et al. (2009) Studies 1 to 7 | 1 | Not reported | 53 | Not reported | Not reported |
| **Digital dermatitis detection** | | | | | |
| Alsaaod et al. (2014) | 8 | Convenience sample (the next eight farms where routine claw-trimming was scheduled). | 133 | Not reported | Not reported |
| Relun et al. (2011) | 4 | Not reported | 242 | Not reported | Not reported |
| Rodriguez-Lainz et al. (1998) | 1 | Availability of personnel and equipment. | 117 | All milking cows in the herd | Not reported |
| Stokes et al. (2012b) Studies 1 & 2 | 3 | Herds were endemically infected with digital dermatitis, and herdsmen were willing to allow a researcher to examine cows for | 80 | In the milking parlour one cow per row was selected for inspection. | There were two groups of cows: i) cows with no skin lesions on the hind feet (control), and ii) cow with a digital dermatitis lesion on one or |

| Author | No. dairy farms | Dairy farm selection criteria | No. cows | Cow selection criteria | Spectrum of disease in population |
|---|---|---|---|---|---|
| | | a period of four months. | | | both of the hind feet |
| Thomsen et al. (2008a) | 3 | Convenience sample (cows were housed in loose housing system). | 393 | All lactating dairy cows on each farm | Not reported |

Table 3-14: Population parameters from each study.

| Author | Cow breed | Feeding | Housing | Parity no. (mean) | Daily milk yield (mean) | Annual milk yield (mean) |
|---|---|---|---|---|---|---|
| **Lameness detection** | | | | | | |
| Leach et al. (2009) | Simmental/Fleckvieh, Holstein, Pinzgauer | Hay & pasture | Tie-stall | NR | NR | NR |
| Thomsen (2009) | Danish Holstein | NR | Free-stall | NR | NR | NR |
| **Foot lesion detection** | | | | | | |
| Alsaaod and Buscher (2012) | Holstein | TMR | Free-stall | 1.5 | NR | 8,687 kg |
| Bicalho et al. (2007a) Studies 1 & 2 | Holstein | TMR | Free-stall | NR | NR | NR |
| Main et al. (2012) | NR | NR | NR | NR | NR | NR |
| Stokes et al. (2012a) | NR | NR | NR | NR | NR | NR |
| **Sole ulcer detection** | | | | | | |
| Chapinal et al. (2009) Studies 1 to 7 | Holstein | TMR | Free-stall | 2.6 | 38.3 | NR |
| **Digital dermatitis detection** | | | | | | |
| Alsaaod et al. (2014) | Mixed breed | NR | Tie-stall | NR | NR | 8,355 Kg |
| Relun et al. (2011) | NR | NR | NR | NR | NR | NR |
| Rodriguez-Lainz et al. (1998) | NR | NR | NR | NR | NR | NR |
| Stokes et al. (2012b) Studies 1 & 2 | Holstein Friesian | NR | NR | NR | NA | 8,400kg |
| Thomsen et al. (2008a) | NR | NR | Loose housing | NR | NR | NR |

TMR: total mixed ration, NR: not reported.

### *Overall methodological quality of studies*

Figure 3-2 summarises the results of the methodological quality assessment. The primary reviewer's judgement for the signaling questions for each study is detailed in Appendix 8. No single study could be classified as being at low risk of bias across all domains. In the animal selection domain, eight studies (40%) were considered to have high risk of bias and concerns for applicability. Twelve studies (60%) were considered to have unclear risk of bias and concerns for applicability. No studies were considered to have low risk of bias for the animal selection domain.

In the index test domain, four studies (20%) were considered to have high risk of bias, six studies (30%) were considered to have low risk of bias and 10 studies (50%) were considered to have an unclear risk of bias. In the reference test domain, eight studies (40%) were considered to have high risk of bias, two studies (10%) were considered to have low risk of bias and 10 studies (50%) were considered to have unclear risk of bias. Concerns for applicability of the index test and reference test domains were judged to be of low concern for all studies. In the flow and timing domain, two studies (10%) were considered to have high risk of bias, 13 studies (65%) were considered to have low risk of bias, and five studies (25%) were considered to have an unclear risk of bias.

### *Sensitivity and specificity of the index tests*

The Se and Sp values reported for each index test are summarised in Table 3-15. Where there was more than one comparison of the index test and reference test within a study, the range of Se and Sp values are reported. Full details of each individual comparison (including specific settings, TP, FP, TN, FN, number of units excluded from analysis, and exclusion justification for each comparison) are reported in Appendix 9.

### *Practical features of the index tests*

The practical features of the index tests are summarised in Table 3-16. One test was automatic while the remaining tests (n = 19) were manually operated (using human effort/observation rather than an electrical or electronic device). Of the manually operated tests, the majority involved subjective interpretation (n = 15) by the operator performing the test. No studies reported the cost associated with the test in question and only two studies reported the time taken, per cow, to carry out the procedures involved with using the test in question.

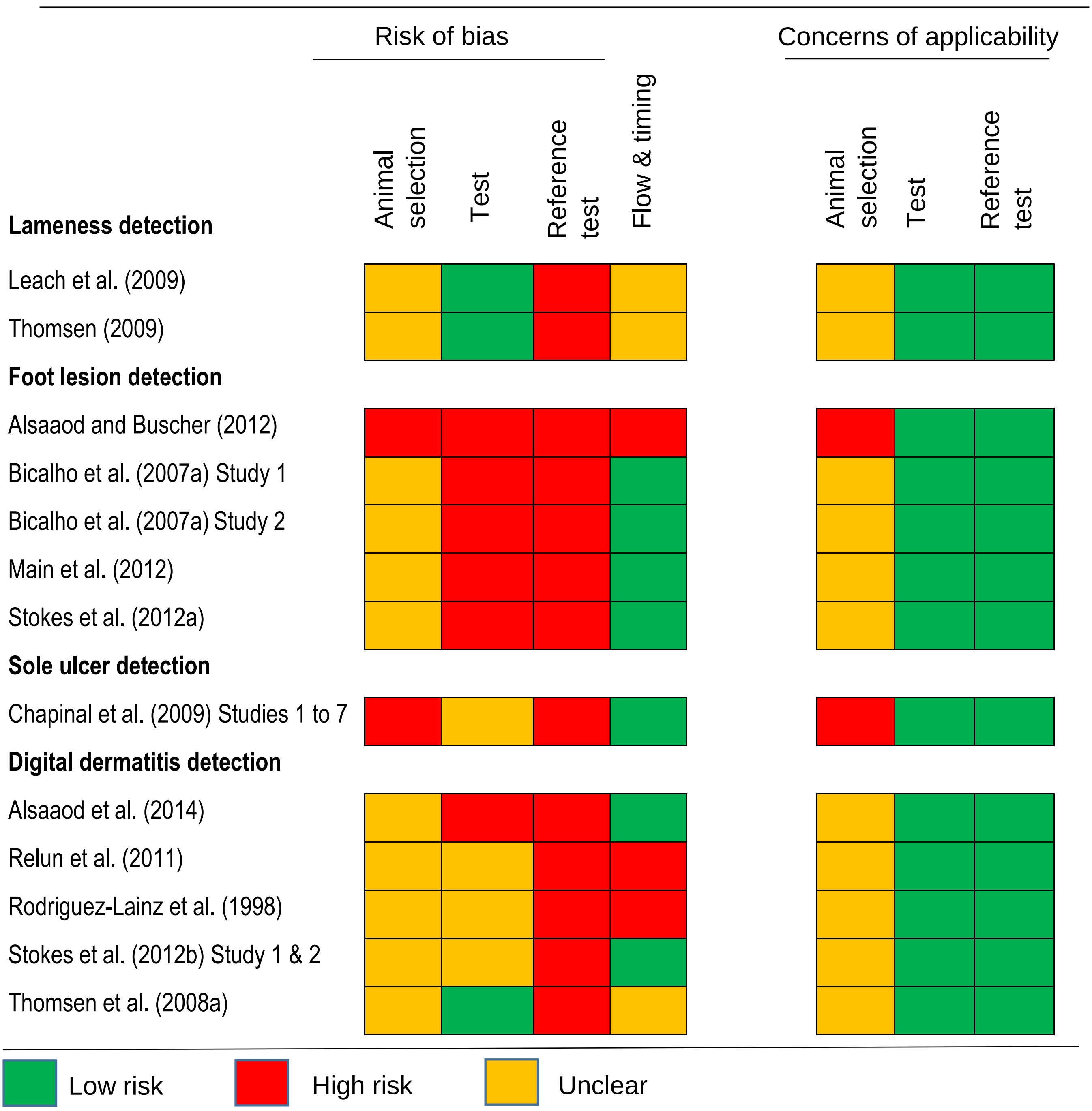


Figure 3-2: Reviewer's judgement of risk of bias and applicability concerns for each study using the protocol presented in Appendix 8.

Table 3-15: Reported sensitivity and specificity values of each comparison for each test. Where there was more than one comparison, the range of sensitivity and specificity values are reported.

| Author | Test | Unit of analysis | No. of units included in analysis | Sensitivity | Specificity |
|---|---|---|---|---|---|
| **Lameness detection** | | | | | |
| Leach et al. (2009) | Observation of lameness indicators | Cow | 95 | 0.54 | 0.93 |
| Thomsen (2009) | Observation of arched back | Cow | 454 | 0.50 | 0.86 |
| **Foot lesion detection** | | | | | |
| Alsaaod and Buscher (2012) | Infra-red thermography | Hind foot | 24 | 0.81 - 0.86 | 0.56 - 0.83 |
| Bicalho et al. (2007a) Study 1 | Locomotion scoring system (scale 1-5) | Cow | 518 | 0.05 – 0.94 | 0.28 – 0.99 |
| Bicalho et al. (2007a) Study 2 | Force plate system | Cow | 518 | 0.24 – 0.35 | 0.85 - 0.95 |
| Main et al. (2012) | Infra-red thermography | Hind foot | 143 | 0.72 - 0.78 | 0.73 - 0.78 |
| Stokes et al. (2012a) | Infra-red thermography | Hind foot | 82 | 0.80 – 0.93 | 0.49 – 0.73 |
| **Sole ulcer detection** | | | | | |
| Chapinal et al. (2009) Study 1 | Observation of abduction and adduction | Cow | 53 | 0.55 | 0.45 |
| Chapinal et al. (2009) Study 2 | Observation of back arch | Cow | 53 | 0.46 | 0.68 |
| Chapinal et al. (2009) Study 3 | Observation of head bob | Cow | 53 | 0.71 | 0.62 |
| Chapinal et al. (2009) Study 4 | Observation of tracking up | Cow | 53 | 0.38 | 0.60 |
| Chapinal et al. (2009) Study 5 | Observation of joint flexion | Cow | 53 | 0.54 | 0.70 |
| Chapinal et al. (2009) Study 6 | Observation of asymmetric gait | Cow | 53 | 0.54 | 0.70 |
| Chapinal et al. (2009) Study 7 | Observation of reluctance to bear weight | Cow | 53 | 0.54 | 0.75 |
| **Digital dermatitis detection** | | | | | |
| Alsaaod et al. (2014) | Infra-red thermography | Cow | 133 | 0.60 - 0.89 | 0.63 - 0.67 |
| Relun et al. (2011) | Visual inspection in milk parlour with swivelling mirror and powerful headlamp | Hind foot | 484 | 0.9 | 0.8 |

| Author | Test | Unit of analysis | No. of units included in analysis | Sensitivity | Specificity |
|---|---|---|---|---|---|
| Rodriguez-Lainz et al. (1998) | Visual inspection in milk parlour | Cow | 117 | 0.72 | 0.99 |
| Stokes et al. (2012b) Study 1 | Visual inspection in milk parlour | Hind foot | 160 | 1 | 0.99 |
| Stokes et al. (2012b) Study 2 | Visual inspection in milk parlour using borescope | Hind foot | 160 | 1 | 1 |
| Thomsen et al. (2008a) | Visual inspection in milk parlour | Hind foot | 393 | 0.65 | 0.84 |

Table 3-16: Practical features of the tests including mode of operation, interpretation, and time requirements.

| Author, year | Manual or automatic operation[1 & 2] | Subjective or objective interpretation[3 & 4] | Time required to operate test/cow |
|---|---|---|---|
| **Lameness detection** | | | |
| Leach 2009 | Manual | Subjective | Not reported |
| Thomsen (2009) | Manual | Subjective | Not reported |
| **Foot lesion detection** | | | |
| Alsaaod and Buscher (2012) | Manual | Objective | Not reported |
| Bicalho et al. (2007a) Study 1 | Manual | Subjective | Not reported |
| Bicalho et al. (2007a) Study 2 | Automatic | Objective | Not reported |
| Main et al. (2012) | Manual | Objective | Not reported |
| Stokes et al. (2012a) | Manual | Objective | Not reported |
| **Sole ulcer detection** | | | |
| Chapinal et al. (2009) Studies 1 to 7 | Manual | Subjective | Not reported |
| **Digital dermatitis detection** | | | |
| Alsaaod et al. 2014 | Manual | Objective | Not reported |
| Relun et al. (2011) | Manual | Subjective | 30 – 60 seconds |
| Rodriguez-Lainz et al. (1998) | Manual | Subjective | Not reported |
| Stokes et al. (2012b) Studies 1 & 2 | Manual | Subjective | Not reported |
| Thomsen et al. (2008a) | Manual | Subjective | 15 seconds |

[1] Manual operation: using human effort/observation rather than an electrical or electronic device; [2]automatic operation: a device or process working by itself with little or no direct human control; [3]subjective interpretation: based on a given person's opinion; [4]objective interpretation: uninfluenced by a given person's opinion, i.e., based on facts, is measurable or observable.

### 3.5.3. Study summary

The following section provides a summary of each study included in the review. Sources of bias (known and unclear) are identified to determine the overall quality of each study and therefore the quality of the reported Se and Sp values (Table 3-17).

#### *Tests used to detect lameness*

##### Observation of two or more lameness indicators - Leach et al. (2009)

The objective of this study was to develop a lameness detection method for cows kept in tie-stalls and to validate it against a published LCSS. Although two comparisons were conducted using this test, only one (the first reported) was investigated in this review. This was because a different observer performed the test in each comparison, meaning that each comparison would need to have been treated as an independent test. This study was conducted across four dairy farms using a study population of 95 cows. No details of farm or cow selection criteria were provided, nor were details of the study population health status (spectrum of disease). An experienced observer performed the reference test (a 5-point LCSS). The Se of the index test was 0.68 and Sp was 0.96. There was insufficient information to determine the presence or absence of selection, spectrum and recovery or disease progression biases.

##### Observation of an arched back - Thomsen (2009)

The objective of this study was to test the hypothesis that a clinically lame cow would have an arched back when standing. A single comparison was conducted across three dairy farms using a study population of 454 cows that were housed in free stalls. No details of farm or cow selection criteria were provided, nor were details of the study population health status. All observations were made on a slatted concrete floor. Arching of the back was not recorded when a cow was standing in a cubicle, eating at the feed bunk, urinating or defecating. An experienced observer used a 5-point LCSS as a reference test. The Se of the index test was 0.50 and the Sp was 0.86. This study was susceptible to diagnostic review bias because of inappropriate blinding between the index and reference tests. There was insufficient information to determine the presence or absence of selection, spectrum and recovery or disease progression biases.

### *Tests used to detect foot lesions*

#### Infra-red thermography - Alsaaod and Buscher (2012)

The objective of this study was to investigate the use of IRT as a tool to detect lameness in dairy cows. Two comparisons were conducted at one dairy farm using a study population of 24 randomly selected cows. The infra-red thermograph was used at a distance of 0.5m to measure the maximal surface temperature of the coronary band and skin on the washed hind feet (n = 48) of the dairy cows. The first comparison used hind feet pre-trimming and the second comparison used hind feet post-trimming. Visual inspection was used as the reference test; however, the operator and skill level were not reported. The Se and Sp for the test in these two comparisons were 0.86 and 0.56 and 0.81 and 0.83, respectively. Both comparisons were at risk of threshold bias because the threshold temperature was not pre-determined and recovery bias because treatment was not withheld until both the test and reference test had been performed. There was insufficient information to determine the presence or absence of misclassification and diagnostic review biases.

#### Locomotion scoring system: 1-5 scale - Bicalho et al. (2007a): Study 1

The objective of this study was to evaluate the performance of a LCSS in the detection of painful digit lesions. Four comparisons were conducted using one dairy farm and a study population of 518 dairy cows. No details of farm or cow selection criteria were provided, nor were details of the study population health status. The four comparisons each used a different LCS threshold for determining lameness (LCS >1 = considered lame if the LCS was 2 or greater; LCS >2 = considered lame if the LCS was 3 or greater; LCS >3= considered lame if the LCS was 4 or greater; and, LCS >4 = considered lame if the LCS was 5). Three veterinarians performed the reference test (visual inspection); however, concordance between the veterinarians was not reported. The Se for the test in these four comparisons ranged from 0.0149 to 0.94, and the Sp from 0.28 to 0.99. There was potential risk of diagnostic review bias because of inappropriate blinding between the test and reference test. There was insufficient information to determine the presence or absence of selection, spectrum and misclassification biases.

#### Force plate system Bicalho et al. (2007a): Study 2

The objective of this study was to evaluate the performance of a force plate system for the detection of painful digit lesions. Using the force plate system, cows walk over a sensor platform that analyses the force and duration of each step providing a score for each hind limb. Ten comparisons were conducted using one dairy farm and a study population of 518 dairy cows. No details of farm or cow selection criteria were provided, nor were details of the study population health status. The ten comparisons each used a different threshold (score) for determining lameness (Appendix 9). Three veterinarians performed the reference test (visual inspection); however, concordance between the veterinarians was not reported. The Se for the test for these ten comparisons ranged from 0.20 to 0.35, and the Sp from 0.85 to 0.95. There was potential risk of diagnostic review bias because of inappropriate blinding between the test and reference test. There was insufficient information to determine the presence or absence of selection, spectrum and misclassification biases.

#### Infra-red thermography - Main et al. (2012)

The objective of this study was to investigate the relationship between lesions and skin temperature of the plantar aspect of cow's feet using IRT. Two comparisons were conducted across six dairy farms, using a study population of 143 dairy cows. Dairy cows were selected if they were undergoing routine foot trimming. The selection criteria for the farms were not reported. The infra-red thermograph was used at a distance of 15cm to measure the temperature of the plantar aspect of each unwashed hind foot (n = 286) of each cow while in standing position. The first comparison used a temperature threshold of 25.5˚, while the second comparison used a temperature threshold of 25.25˚C. An experienced foot trimmer performed the reference test (visual inspection). The Se and Sp for the test in these two comparisons were 0.72 and 0.73 and 0.78 and 0.78, respectively. Both trials were at risk of threshold bias because the threshold temperature was not pre-determined, and diagnostic review bias because of inappropriate blinding between the test and reference test. There was insufficient information to determine the presence or absence of misclassification, selection and spectrum biases.

#### Infra-red thermography - Stokes et al. (2012a)

The objective of this study was to examine the potential of using IRT as a tool for screening the presence of digital dermatitis on cows' feet. However, the study found that digital dermatitis and all other identified foot lesions were associated with an elevated temperature when compared to feet without lesions. Therefore, the authors modified the aim of the study to examine IRT as a detection tool for any foot lesion. Three comparisons were performed across four dairy farms. The selection criteria for these farms were: i) herds were endemically infected with digital dermatitis, and ii) herdsmen were willing to allow a researcher to examine cows on two consecutive days each week for a period of four months. The study population consisted of 82 dairy cows. To select these cows, a sampling strategy was employed where during each afternoon visit, while in the milking parlour; one cow per row was selected for inspection. Starting at one end of each row, the cow's foot was cleaned with a high-pressure hose until a cow eligible for one of two groups was identified. The two groups were: i) cow with no skin lesions on the hind feet (control), or ii) cow with a digital dermatitis lesion on one or both of the hind feet. Up to four cows were selected each afternoon. The IRT threshold used was 27, 22, and 21˚C for the three comparisons, respectively. The first two comparisons were while the cows were in standing position, while in the third comparison the foot was lifted. Visual inspection was used as the reference test; however, the reference test operator and skill level were not reported. The Se for the test in these three comparisons ranged from 0.80 to 0.93 and the Sp from 0.49 to 0.73. All three comparisons were at risk of threshold bias because the threshold temperature was not pre-determined, and diagnostic review bias because of inappropriate blinding between the test and reference test. There was insufficient information to determine the presence or absence of misclassification and spectrum biases.

### *Tests used to detect sole ulcer*

#### Observation of gait characteristics - Chapinal et al. (2009)

##### Abduction/adduction - Study 1

The objective of this study was to investigate the association between the gait characteristic abduction/adduction and the presence of sole ulcers. A single comparison was conducted at one dairy farm using a study population of 53 cows. No details of farm or cow selection criteria were provided, nor were details of the study population health status. An experienced observer performed the reference test (visual inspection). The Se of the test was 0.55 and the Sp was 0.45. This study was susceptible to spectrum bias because the study population was not a representative sample and inappropriate exclusions were made (i.e., primiparous cows were removed because they consistently had lower locomotion scores than multiparous cows), and diagnostic review bias because of inappropriate blinding between the test and reference test. There was insufficient information to determine the presence or absence of selection, and misclassification biases.

#### Back arch - Study 2

The objective of this study was to investigate the association between the gait characteristic back arch and the presence of sole ulcers. The Se of the test was 0.46 and the Sp was 0.68. All other details are as reported for Study 1.

#### Head bob - Study 3

The objective of this study was to investigate the association between the gait characteristic head bob and the presence of sole ulcers. The Se of the test was 0.71 and the Sp was 0.62. All other details are as reported for Study 1.

#### Tracking up - Study 4

The objective of this study was to investigate the association between the gait characteristic tracking up and the presence of sole ulcers. The Se of the test was 0.38 and the Sp was 0.60. All other details are as reported for Study 1.

#### Joint flexion - Study 5

The objective of this study was to investigate the association between the gait characteristic joint flexion and the presence of sole ulcers. The Se of the test was 0.54 and the Sp was 0.70. All other details are as reported for Study 1.

#### Asymmetric gait - Study 6

The objective of this study was to investigate the association between the gait characteristic asymmetric gait and the presence of sole ulcers. The Se of the test was 0.54 and the Sp was 0.70. All other details are as reported for Study 1.

#### Reluctance to bear weight - Study 7

The objective of this study was to investigate the association between the gait characteristic joint flexion and the presence of sole ulcers. The Se of the test was 0.54 and the Sp was 0.75. All other details are as reported for Study 1.

### *Tests used to detect digital dermatitis*

#### Infra-red thermography - Alsaaod et al. (2014)

The objective of this study was to evaluate IRT as a tool for the detection of digital dermatitis lesions in dairy cows. Two comparisons were conducted across eight dairy farms. These farms were a convenience sample (i.e., the next eight farms where routine claw-trimming was scheduled were selected for the study). A study population of 133 dairy cows was recruited. The selection criteria for the cows were not reported. IRT was used to measure the maximal surface temperatures of the coronary band and skin on unwashed feet of the cows. The first comparison assessed the hind feet only and used a temperature threshold of 0.99˚C. The second comparison assessed both fore and hind feet and used a temperature threshold of 0.85˚C. Two trained operators performed the reference test (visual inspection), however, concordance between the operators was not reported. The Se and Sp for the test in these two comparisons were 0.89 and 0.67 and 0.60 and 0.63, respectively. Both comparisons were at risk of threshold bias because the threshold temperature was not pre-determined, and diagnostic review bias because of inappropriate blinding between the test and reference test. There was insufficient information to determine the presence or absence of selection, spectrum, and misclassification biases.

#### Visual inspection in a milking parlour with a swiveling mirror and powerful headlamp - Relun et al. (2011)

The objective of this study was to assess the use of a swiveling mirror and powerful headlamp to detect and score digital dermatitis lesions in the milking parlour using the M-stage scoring system. A single comparison was conducted across four dairy farms using a study population of 242 cows. No details of farm or cow selection criteria were provided, nor were details of the study population health status. Five operators performed the test and the digital dermatitis score was determined by having all five observers reach a general consensus. The concordance between these observers was moderate (*k* = 0.51). The 5-point M-stage digital dermatitis scoring system was also used as the reference test. Six observers on the first two farms and seven on the remaining two farms carried out the reference test. Similarly, the digital dermatitis score was determined by having all observers reach a general consensus. Concordance between these observers was not reported. The Se of the test was 0.90, and the Sp was 0.80. There was a potential risk of diagnostic review bias because of inappropriate blinding between the test and reference test and incorporation bias because the test formed part of the reference test (i.e., the 5-point M-stage digital dermatitis scoring system was used for both the test and reference test). There was insufficient information to determine the presence or absence of misclassification, selection and spectrum biases.

#### Visual inspection in a milking parlour - Rodriguez-Lainz et al. (1998)

The objective of this study was to evaluate a milking parlour screening method for the detection of digital dermatitis. A single comparison was conducted on one dairy farm using a study population of 117 cows. The selection of farm was based on availability of personnel and required equipment. All milking cows in the herd were inspected. Digital dermatitis lesions were identified and staged using colour pictures (the pictures were used to standardise the classification of lesions by different observers). The number of operators, their experience and level of concordance were not reported. Visual inspection was used as the reference test; however, the operator and skill level were not reported. The Se and Sp for the test was 0.72 and 0.99, respectively. There was a potential risk of recovery or disease progression bias because of the reported delay between the performance of the test and reference test. There was insufficient information to determine the presence or absence of selection, spectrum and misclassification biases.

#### Visual inspection in a milking parlour - Stokes et al. (2012b): Study 1

The objective of this study was to evaluate the performance of visual inspection of cow's feet in the milking parlour for detecting and classifying digital dermatitis lesions. A single comparison was conducted across three dairy farms. The selection criteria for these farms were: i) herds were endemically infected with digital dermatitis, and ii) herdsmen were willing to allow a researcher to examine cows weekly for a period of 12 weeks. The study population consisted of 80 dairy cows. To select these cows, a sampling strategy was employed where during each weekly visit, while in the milking parlour; one cow per row was selected for inspection. Starting at one end of each row, the cow's foot was cleaned off with a high-pressure hose until a cow eligible for one of two groups was identified. The two groups were: i) cow with no skin lesions on the hind feet (control), or ii) cow with a digital dermatitis lesion on one or both of the hind feet. Up to four cows were selected at one time. Visual inspection was used as the reference test; however, the operator and skill level were not reported. The Se and Sp for the test was 1.00 and 0.99, respectively. There was a potential risk of diagnostic review bias because of inappropriate blinding between the test and reference test and incorporation bias because the test formed part of the reference test (i.e., the stage of infection, depth, colour and size of lesions were assessed and measured the same for both the test and reference test). There was insufficient information to determine the presence or absence of misclassification and spectrum biases.

#### Visual inspection in a milking parlour using a borescope - Stokes et al. (2012b): Study 2

The objective of this study was to evaluate the performance of using a borescope in a milking parlour for detecting and classifying digital dermatitis lesions in dairy cows. The Se and Sp of the test were each 1.00. All other details are as reported for Stokes et al. (2012b) Study 1.

### Visual inspection in a milking parlour Thomsen et al. (2008a)

The objective of this study was to evaluate a rapid screening method for digital dermatitis in the milking parlour without using any specialised tools. A single comparison was conducted across three dairy farms. The selected farms were a convenience sample based on a single selection criterion: cows were housed in a loose housing system. On each farm, all lactating dairy cows (n = 393) were included. The washed hind feet of the cows were inspected using a flashlight and a Dictaphone was used to record the scores of identified lesions. An observer who was trained in scoring digital dermatitis lesions performed the reference test. The Se of the test was 0.65 and the Sp was 0.84. There was a potential risk of incorporation bias because the test formed part of the reference test (i.e., the digital dermatitis scoring system used was the same for both the test and reference test). There was insufficient information to determine the presence or absence of selection, spectrum and recovery or disease progression biases.

Table 3-17: Sources of bias (known and unclear) identified in each study.

| Author (Year) | Test | Known sources of bias | Unclear biases | Is this study free from bias? |
|---|---|---|---|---|
| **Lameness detection** | | | | |
| Leach et al. (2009) | Visual observation of two or more lameness indicators | Misclassification | Selection, spectrum and recovery or disease progression | Unclear |
| Thomsen (2009) | Observation of an arched back | Diagnostic review, misclassification | Selection, spectrum and recovery or disease progression | No |
| **Foot lesion detection** | | | | |
| Alsaaod and Buscher (2012) | Infra-red thermography | Threshold bias and misclassification | Diagnostic review, and recovery or disease progression | No |
| Bicalho et al. (2007a) Study 1 | Locomotion scoring | Diagnostic review and misclassification | Selection and spectrum | No |
| Bicalho et al. (2007a) Study 2 | Force plate system | Diagnostic review and misclassification | Selection and spectrum | No |
| Main et al. (2012 647) | Infra-red thermography | Threshold, diagnostic review and misclassification | Selection and spectrum | No |
| Stokes et al. (2012a) | Infra-red thermography | Threshold, diagnostic review, incorporation and misclassification | Spectrum | No |
| **Sole ulcer detection** | | | | |
| Chapinal et al. (2009) Study 1 | Observation of gait characteristic abduction/adduction | Spectrum and misclassification | Selection | No |
| Chapinal et al. (2009) Study 2 | Observation of gait characteristic back arch | Spectrum and misclassification | Selection | No |
| Chapinal et al. (2009) Study 3 | Observation of gait characteristic head bob | Spectrum and misclassification | Selection | No |
| Chapinal et al. (2009) Study 4 | Observation of gait characteristic tracking up | Spectrum and misclassification | Selection | No |
| Chapinal et al. (2009) Study 5 | Observation of gait characteristic joint flexion | Spectrum and misclassification | Selection | No |

| Author (Year) | Test | Known sources of bias | Unclear biases | Is this study free from bias? |
|---|---|---|---|---|
| Chapinal et al. (2009) Study 6 | Observation of gait characteristic asymmetric gait | Spectrum and misclassification | Selection | No |
| Chapinal et al. (2009) Study 7 | Observation of gait characteristic reluctance to bear weight | Spectrum and misclassification | Selection | No |
| **Digital dermatitis detection** | | | | |
| Alsaaod et al. (2014) | Infra-red thermography | Threshold and misclassification | Selection, spectrum, and recovery or disease progression | No |
| Relun et al. (2011) | Visual inspection in a milking parlour with swiveling mirror and powerful headlamp | Misclassification and diagnostic review | Selection, spectrum, and recovery or disease progression | No |
| Rodriguez-Lainz et al. (1998) | Visual inspection in a milking parlour | Disease recovery and misclassification | Selection and spectrum, | No |
| Stokes et al. (2012b) Study 1 | Visual inspection in a milking parlour | Diagnostic review, incorporation and misclassification | Spectrum | No |
| Stokes et al. (2012b)b Study 2 | Visual inspection in milking parlour using a borescope | Diagnostic review, incorporation and misclassification | Spectrum | No |
| Thomsen et al. (2008a) | Visual inspection in a milking parlour | Incorporation and misclassification | Selection, spectrum, disease recovery | No |

### 3.5.4. Discussion

This systematic review highlighted two important shortcomings of the included studies: i) incomplete reporting of pertinent information, and ii) potential sources of bias. Due to these issues, the studies lacked sufficient evidence to determine the quality of the reported Se and Sp values and the suitability of each test for use by dairy farmers. Therefore, it was not appropriate to compare the performance of the tests and subsequently make a recommendation of those suitable for implementation on the farm. The major issues regarding study quality and on farm implementation are discussed here.

#### *Quality of the included studies*

Incomplete reporting limited the methodological quality assessment of the studies. Where sufficient information was not reported, it was difficult to differentiate between studies that were methodologically robust and those that applied poor methods leading to biased and unreliable outcomes.

The animal selection domain was of particular concern with 60% of studies assessed as having an unclear risk of bias. This was because: i) most studies (65%) failed to describe how animals were selected for inclusion in the study, and ii) all studies failed to describe the spectrum of disease of the recruited animals. These two pieces of information are crucial in the interpretation of diagnostic test accuracy because Se and Sp are not constant properties of a diagnostic test (Montori et al. 2005). Rather, Se and Sp will vary with the spectrum of disease within a given population, therefore in a different population, Se and Sp are likely to be different (Montori et al. 2005). This makes it difficult to recommend the tests investigated in this systematic review to dairy farmers because the accuracy results reported may have limited applicability to the context in which the dairy farmer will use the test in question.

There was high risk of bias in all studies. The most common sources of bias were misclassification, diagnostic review and spectrum bias. Of particular concern in all studies was the lack of an appropriate reference test and therefore the potential for misclassification bias. The reference tests were considered inappropriate for a number of reasons. First, it is ideal that the reference test used in a study of diagnostic test accuracy is the best available method for establishing the presence or absence of the target condition (Whiting et al. 2003). However, determining what constitutes “the best available method” and whether that method should be considered as a reference test is often left up to the judgement of the investigators. For example, in the case of LCS, there are several scoring systems available for consideration with no consensus on the best available method. The findings of this study suggest that where there are several reference tests available, the investigators need to justify their decision for the use of a particular reference test. There was only one study in this systematic review that provided such justification (Thomsen 2009), suggesting that LCS is an appropriate method for the detection of lameness in dairy cows. However, the investigators failed to clarify whether this referred to the specific LCSS used in their study or all available LCSS's.

Second, the reference tests used in the studies included in this systematic review (LCS and visual inspection) were highly subjective. Therefore, test performance would be expected to be highly variable depending on the level of training and experience of the operator and their individual interpretation (Van Hertem et al. 2014). In a number of studies (Rodriguez-Lainz et al. 1998; Bicalho et al. 2007a; Alsaaod & Buscher 2012; Stokes et al. 2012b, 2012a), information regarding operator training and experience was not provided, therefore it was difficult to judge the quality of these reference tests.

Finally, the reference tests used were imperfect tests. In the absence of a perfect reference test, Se and Sp estimates are probably biased to some extent (LaJoie et al. 2005). This makes Se and Sp unreliable for determining the accuracy of tests (LaJoie et al. 2005). LaJoie et al. (2005) suggest that in the absence of a perfect reference test, latent class analysis can be used to determine the unidentified cases or subgroups within a population. Alternatively, measuring the extent of agreement between the test under investigation and the reference test has been suggested as a means of avoiding Se and Sp. However, there are a number of concerns to be raised with using agreement data in the context of diagnostic test accuracy. First, agreement data are typically performed between two raters, rather than two tests, who each classify *N* items into *C* mutually exclusive categories (Kraemer et al. 2002). For example, if two veterinarians are asked to stage digital dermatitis lesions on the feet of 50 dairy cows using the M-stages scoring system, the level of agreement between the two raters is achieved by comparing their classification with each other. Second, agreement data should be used when two raters are using the same scale, classification, instrument, or procedure (Kottner et al. 2011). Therefore, because studies of diagnostic test accuracy are comparing two alternate tests, it would be inappropriate to use agreement data. Finally, if agreement data were used to compare two tests, it is questionable how useful the outcome would be. For example, two tests under investigation might have perfect or near perfect agreement, but they could both be poor performing tests (i.e. with Se and Sp of 50%). Therefore, agreement data has limited applicability in the context of diagnostic test accuracy and investigators are encouraged to use latent class analysis methods.

Diagnostic review bias, where the same operator performed both the test under investigation and the reference test, was detected in several studies (Bicalho et al., 2007; Thomsen, 2009; Relun et al., 2011; Main et al., 2012; Stokes et al., 2012a). This has the potential to result in an overestimation of test accuracy. This can be avoided if a different operator performs each test. Spectrum bias was detected in the seven studies conducted by Chapinal et al. (2009), where primiparous cows were removed because they had lower LCS's than the multiparous cows. The use of the test in a population with higher LCS's would be expected to lead to a higher probability of detection than cows with less obvious lameness, resulting in an overestimation of test accuracy.

Due to the lack of sufficient information and the identified biases, the overall quality of the included studies was poor. The literature demonstrates that primary studies with poor methodological quality are susceptible to over estimating test performance (Lijmer et al. 1999; Rutjes et al. 2006). Therefore, there is limited confidence in the quality of the Se and Sp values reported for the tests investigated in this systematic review and they cannot be recommended to be used on dairy farms.

### On farm implementation

Borchers and Bewley (2015) and Russell and Bewley (2013) identified features that are important to dairy farmers in deciding whether to implement a technology on the farm. Two of the most important features were: i) the total investment cost, and ii) simplicity and ease of use. Horseman et al. (2014) highlighted the importance of time taken for the detection of lame cows in dairy herds. Therefore, it is pertinent to consider these features in assessing the appropriateness of the evaluated tests for implementation in dairy herds.

The cost of incorporating a new technology or method into farm practices includes not only the fixed costs involved with purchasing the equipment (if applicable), but also variable costs such as training and labour. Neither of these costs were evaluated for any of the tests investigated in this systematic review.

All but one of the tests evaluated in this systematic review were manual methods. While the initial cost of manual methods may be low (e.g., a LCS system involves no purchase cost), the ongoing costs can be substantial. This is because these methods require special training; are subjective, resulting in variability in performance and outcomes; and they can be time consuming to perform. Further, by the time a foot lesion can be seen visually, the problem may have already existed for some time and therefore had considerable impact on productivity and animal welfare. Automatic technologies have the potential to minimise interruption to dairy farmer's day-to-day practices as the requirement for manual labour is minimised. These technologies are more objective and have the potential to identify foot lesions prior to manifestation of clinical signs and impact on productivity. However; these technologies will likely come at an increased cost to dairy farmers due to their increased complexity.

A series of interviews by Horseman et al. (2014) showed that in terms of performing LCS, time is of major concern for dairy farmers, particularly at certain times of the year. Therefore, dairy farmers desire technologies that are not time consuming with less interruption in daily activities. Two studies included in this systematic review, (Thomsen 2009; Relun et al. 2011), reported the time taken to use the test in question (visual inspection in milking parlour with swivelling mirror and powerful headlamp and visual inspection in milking parlour, respectively). Relun et al. (2011) and Thomsen (2009) reported observation to take 30-60 seconds and 15 seconds per cow, respectively. Although these methods are quick (per cow), the accumulative time for an entire herd may still be impractical for the average dairy farmer to incorporate into their day-to-day practices.

### 3.5.5. Conclusion and recommendations

#### *Implications for practice*

A major objective of this systematic review was to recommend tests for on farm implementation based on their accuracy and practicality for dairy farmers. A number of tests were identified for the detection of lameness, foot lesions, sole ulcers and digital dermatitis; however, no tests were identified for the diagnosis of specific foot lesions. None of the tests reviewed and assessed in this systematic review could be recommended due to incomplete reporting of pertinent information (e.g., animal selection and spectrum of disease, which precluded a thorough methodological quality assessment), and high probability of risk of bias, particularly misclassification bias regarding the quality of the reference test.

#### *Recommendations for future research*

Overall, better reporting is essential to facilitate the assessment of methodological quality of studies. Areas of poor reporting included: eligibility criteria and selection of animals, disease spectrum of selected animals, reference test operator and skill level, and characteristics of dairy herds under investigation (e.g., DIM, feeding, housing and milking systems, parity and productivity). In addition, a considerable number of papers were excluded because no data on Se and Sp estimates were reported. Therefore, authors of studies investigating diagnostic test accuracy for the detection and diagnosis of lameness lesions in dairy cows should be encouraged to use the STARD guidelines (Bossuyt et al. 2015). This will improve the evaluation of the test(s) in question and allow conclusions to be made regarding their potential application at the farm level. Other factors authors should consider reporting include information pertinent to dairy farmer decision making. This includes information such as associated costs, estimated required time per cow and required skills and training.

The quality of the reference tests used in the included studies was of major concern. The reference tests used were highly subjective and several studies failed to provide relevant information such as the level of experience of the operator. Therefore, it was not possible to assess the quality of the reference tests. In order to rigorously assess the quality and accuracy of reference tests, more information about the specific context in which the test has been used is essential. In addition, the reference tests were imperfect, which increases the probability of biased Se and Sp estimates. In the absence of a perfect reference test, alternative analytical methods, such as latent class analysis, can be used to estimate the unidentified cases and reduce the risk of bias.

# 4. Chapter 4: Tele-medicine on the farm – a platform for improved farm worker diagnosis and treatment of foot lesions in dairy cows

## 4.1. Introduction

Foot lesions pose a threat to all dairy cows and often result in pain (O'Callaghan 2003; Whay et al. 2003), lameness (Bicalho et al. 2009), reduced milk yield (Green et al. 2002; Johnson et al. 2003; Reader et al. 2011), and poor reproductive performance (Garbarino et al. 2004; Walker et al. 2008a). These outcomes come at a substantial economic burden to the individual dairy farmer in addition to the cost of treatment.

The prompt detection of foot lesions is crucial in minimising their duration and severity, the risk of repeat cases and the associated impacts (Bell et al. 2006; Reader et al. 2011; Groenevelt et al. 2014). Diagnosis should also be considered important to minimise these outcomes. The literature suggests that dairy farmers are more likely to perform detection and diagnosis of foot lesions independently without veterinarian or other expert opinion (Whitaker et al. 1983; Clarkson et al. 1996; Fabian 2012). However, a number of studies indicate that dairy farmer ability to detect lameness in cows in their herds is relatively poor in comparison to researchers with training in the detection of lame cows (Wells et al. 1993; Espejo et al. 2006; Leach et al. 2010). Therefore, research has been directed towards investigating potential methods to aid dairy farmers in the detection of lameness (Thomsen 2009; Alsaaod & Buscher 2012; Stokes et al. 2012b).

Little research has assessed dairy farmer ability to diagnose foot lesions. Where misclassification occurs, there may be an increased probability of treatment failure. Tele-medicine, formally defined as 'the use of medical information exchanged from one site to another via electronic communications to improve a patient's clinical health status' (The American Telemedicine Association 2016), offers a possible solution to avoid misclassification and treatment failure of foot lesions. Tele-medicine in various forms including tele-radiology, tele-pathology and tele-dermatology, has been adopted in human medicine and has demonstrated capacity for success (Whited et al. 1991; Shin et al. 2014). This study introduces the concept of a tele-foot-health system whereby digital images of lameness lesions were sent via mobile phone technology to a remote veterinarian for assessment. The tele-foot-health system aimed to provide the dairy farmer with a veterinary assisted platform for the diagnosis and treatment of foot lesions in dairy cows.

The objectives of this chapter are to:

- Quantify the level of agreement between an on-site (farm) veterinarian and a dairy farmer in the diagnosis and treatment of lameness lesions.
- Quantify the level of agreement between an on-site veterinarian and a remote veterinarian in the diagnosis and treatment of lameness lesions.

With these objectives, this chapter aims to answer the following research questions:

- To what extent does dairy farmer diagnosis and treatment of foot lesions agree with on-site veterinarian diagnosis and treatment?
- To what extent does remote veterinarian diagnosis and treatment of foot lesions agree with on-site veterinarian diagnosis and treatment?
- Can mobile phone technology be used as a remote consultation tool between a dairy farmer and a remote veterinarian to facilitate correct diagnosis and treatment of foot lesions?

## 4.2. Materials and Methods

### 4.2.1. Ethics approval

Prior to commencing this study, ethical approval was sought from the University of Queensland Animal Ethics Unit. The Approval Number is SVS/082/12. A copy of the ethics approval letter is located in Appendix 10.

### 4.2.2. Study location and animals

This study was conducted between 21 January and 31 December 2013 on a commercially operating dairy herd in Gatton, Queensland Australia. The study herd was chosen based on convenience, consisting on average of 259 dairy cows of mixed age and mixed breed (predominantly Holstein-Friesian). The herd had free access to water and pasture and was supplemented with a total mixed ration to meet production demands as per routine farm practice.

### 4.2.3. Dataset limitations

These data were acquired already extracted from the data collection forms used in the study and entered into a Microsoft Excel® spreadsheet. There was no access to the raw data from these forms; therefore, it was not possible to check for potential data entry errors. These analyses were done four years after data collection and it was not possible to contact the principal investigator Further information on the dataset was only available from the participating remote veterinarian, presenting limitations to follow up questions.

### 4.2.4. Study definitions

#### *Lameness event*

An occasion where a cow was observed to be lame by the dairy farmer during routine farm duties (i.e., as the cows walked in and out of the milking shed and on the laneways, rather than specifically seeking out events). A cow could have more than one lameness event during the study period.

#### *Lesion*

A lesion may be defined as 'any injury, wound, infection, or any structural or other form of abnormality anywhere in the body' (Collins Dictionary of Medicine 2005). In this study, each rater could record one or more lesions per lameness event occurring on one or more limbs. Therefore, the number of lesions recorded by each rater may differ. In the lameness data collection form used in this study the claw was divided into 10 zones (Figure 4-1). In filling out this form, raters were directed to select one zone per lesion. It is unclear from the dataset whether a lesion may have affected more than one zone (i.e., a single lesion was confluent across multiple zones but caused by one disease only). Where a lesion may have occurred over multiple zones it is unknown whether raters treated this as multiple lesions or a single lesion. Therefore, for the purpose of this study, a lesion was defined as follows: a lesion can only affect one zone and can only have one diagnosis (i.e., where one diagnosis was reported in multiple zones, or where multiple diagnoses were reported in one zone, each was classified as an independent lesion).

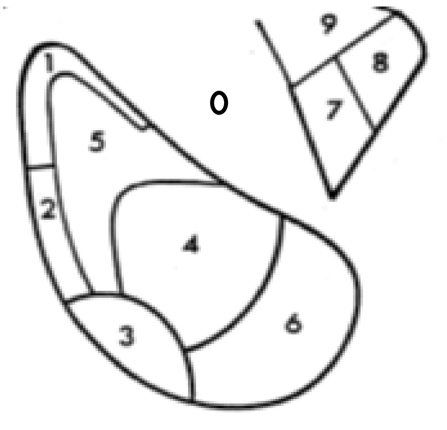


Figure 4-1: Diagram of the cow claw divided into 10 zones as per the lameness data collection form (Greenough 1997).

### 4.2.5. Participants

Participants in the study were two dairy farmers, the farm manager and assistant farm manager (DF) each with 20 years of experience working with dairy cows; an on-site (farm) veterinarian (FV); and a remote veterinarian (RV), with 15 and 43 years of experience as practicing veterinarians, respectively. Although both the farm manager and the assistant manager participated in the recording of observations for data collection, they were considered a collective unit as the assistant farm manager contributed only approximately 10% to the data collection. The participants will be referred to as raters throughout the chapter.

### 4.2.6. Training

Prior to the data collection period the DF received detailed instructions from the FV on when and how to assess for lameness events. The Healthy Hoof Lameness Field Guide (Dairy Australia 2010) was the foundation source for training on lameness identification. In addition, the FV instructed the DF on how to document observed lameness lesions in the herd using the data collection form.

### 4.2.7. Data collection

A lameness data collection form was used by the raters to record data for each lesion they identified. The form consisted of variables collected at both the lameness event and lesion level. The following variables were collected at the lameness event level: date of occurrence of the lameness event and LCS. Variables collected at the lesion level were: limb and claw affected**,** zone of claw, tissue, diagnosis (referred to as classification on the data collection form), treatment, and lesion severity. The following variables were nominal variables (variables with two or more categories with no natural order): limb and claw affected, with 8 categories (left, right, fore, hind and their combinations with medial or lateral claw)**;** zone of claw, with 10 categories; body region, with 10 categories; tissue, with 10 categories; diagnosis (referred to as classification on the data capture form), with 22 categories for the DF and 37 for the veterinarians; and, treatment with 15 categories for the DF and 24 for the veterinarians. The following variables were ordinal variables (variables with two or more categories with a clear order): LCS, scored on a five-point ordinal scale (scale 1 - 5, where 1: normal, 2: slight abnormality, 3: slight lameness, 4: obvious lameness, and 5: severe lameness) and lesion severity, scored on a four-point ordinal scale (scale 1 - 4, where 1: mild, trace; 2: distinct diagnostic sign; 3: marked clinical lesion; and 4: complicated or infected). Each variable used a unique numbering system to code for the different categories. While the codes used held no meaning for nominal variables, the codes used for the two ordinal variables followed the scale defined for each.

Each rater independently recorded their observations for each lesion they identified during a lameness event (i.e., each rater independently determined the number of lesions in each lameness event; therefore, the number of lesions identified is rater-specific). One form was used per lesion identified by each rater.

The form was selected on the basis that it was developed by an international panel. However, for the purpose of this study, the original form (Greenough 1997) was modified in two ways. First, for the veterinarians, the form was modified to include additional categories for treatment. Second, for the DF, the form was also modified to include these additional categories for treatment. In addition, the entire treatment list was simplified to only include options that a typical dairy farmer would have available on the farm. Further, there was a reduction in the number of categories available for making a diagnosis to reflect the anticipated knowledge gap between the DF and FV. The form used by the veterinarians and the form used by the DF are presented in Appendix 11.

The RV received information on the limb and claw affected and the LCS as determined by the FV along with digital images of each affected limb. Therefore, only the following variables applied to the RV: zone of claw, body region, tissue, diagnosis, treatment, and lesion severity.

In addition to these data, cow age, parity number, breed, calving dates and lactation data (total milk yield, protein content and fat content) for the lactation during the study period were collected. These data were obtained from farm records.

### 4.2.8. Study procedure

Once a lame cow was identified by the DF, the cow was drafted for further investigation and a consultation was booked with the FV. During the consultation as the cow was walked to the crush the DF and FV independently assessed and recorded the LCS of the cow. The DF then restrained the cow in the crush and identified and washed the affected limb in preparation for examination and digital photography. However, if the DF and FV disagreed on which limb was lame, the limb as identified by the FV was also prepared and they were both examined.

The cow was then examined for lameness lesions. The DF examined the cow first and independently filled out the lameness data collection form/s. The FV assisted the DF to lift the limb identified by the DF (i.e. the DF did not receive advice or assistance to identify the correct limb or claw affected or to identify lesions). Once the DF had completed the form/s, the FV then examined the cow (selecting the limb and claw that he determined to be affected, which may or may not have been the same as the DF) and completed a separate blinded lameness data collection form/s. Following this, the FV used a ‘smartphone’ digital camera (Samsung ACE®, 3 megapixel camera, South Korea) to capture two alternative views of each affected limb identified as lame in a lameness event.

The DF and FV reports and the images taken by the FV were sent to an independent observer who sent the images to the RV as a Multi-Media Message Service (MMS) along with: i) animal identification number, ii) examination date, iii) cow LCS as per FV observation, and iv) limb and claw affected as per FV observation. The RV then completed his own lameness collection capture form/s using this information. The study procedure is demonstrated in Figure 4-2.

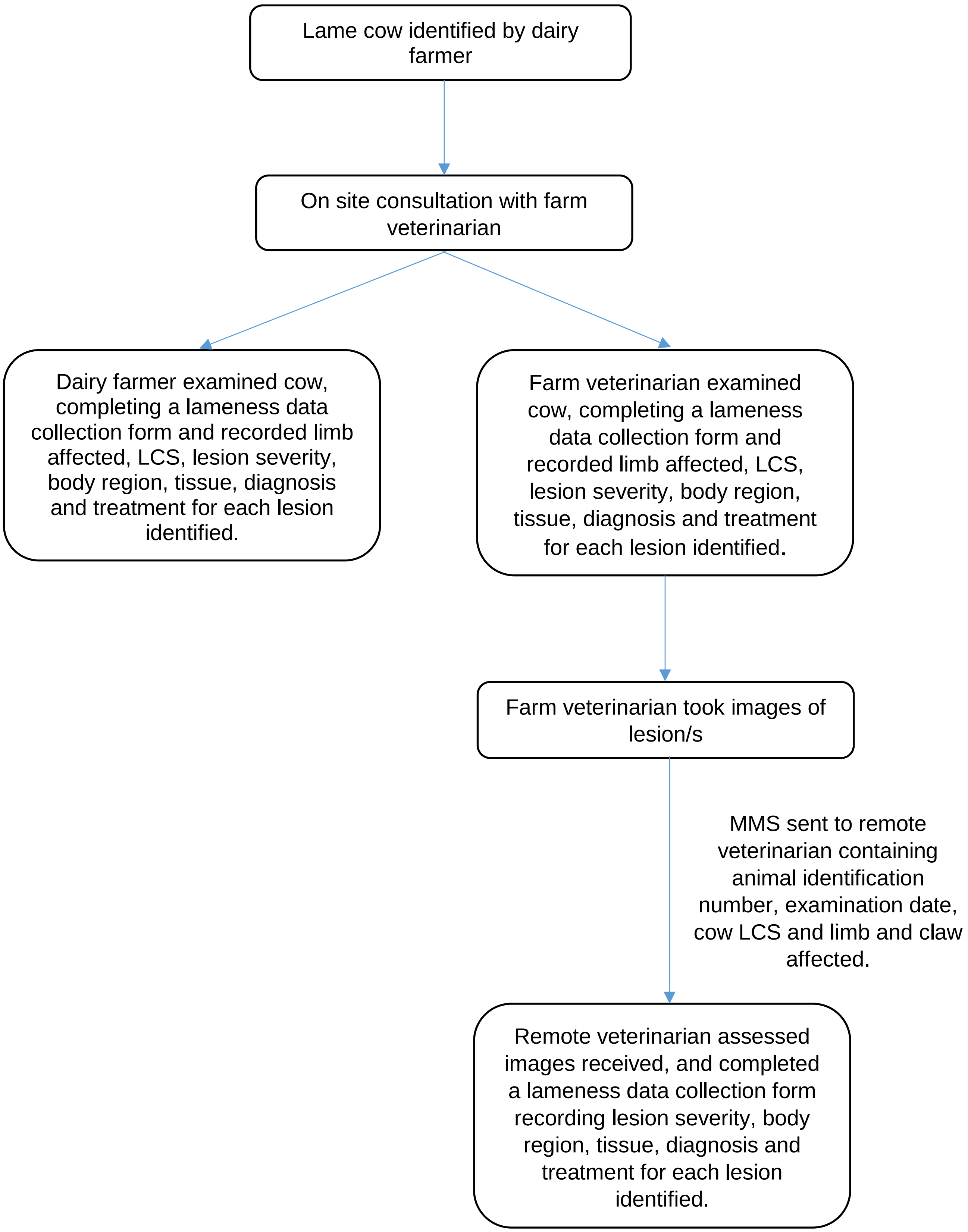


Figure 4-2: Study procedure for data collection. LCS: locomotion score, MMS: multi-media message service.

### 4.2.9. Data management

#### *Initial data presentation*

In the Microsoft excel spreadsheet provided for the study, for each variable described in Section 4.2.6, there were three rater specific variables as per Table 4-1. Presentation of the data in the spreadsheet were as follows: each column consisted of a different rater specific variable (e.g. FV LCS, FV limb and claw affected, FV lesion severity, FV body region, FV tissue, FV diagnosis, FV treatment – these were repeated for each rater) and each row contained a unique lesion (i.e., one row per lesion identified). The number of rows per cow for each lameness event was equal to the maximum number of lesions identified by any one rater. Where one rater may have said more lesions than another in a lameness event, these 'extra' lesions were recorded as normal (no lesion) for any rater who did not identify that number of lesions. A second lameness event for one cow was recorded as a different date.

For example, Table 4-2 demonstrates three cows (cow 367, cow 517 and cow 2118) as rated by the FV. For cow 367, there was one lameness event with three lesions identified. For cow 517, there was one lameness event, with two lesions identified, however, the FV only indicated one lesion (therefore the RV and/or DF identified a second lesion). For cow 2118 there were two lameness events recorded with one lesion each.

Table 4-1: Rater specific variables.

| Variable | | Rater specific variables | |
|---|---|---|---|
| Limb and claw | FV Limb and claw | RV Limb and claw | DF Limb and claw |
| Tissue | FV Tissue | RV Tissue | DF Tissue |
| Body region | FV Body region | RV Body region | DF Body region |
| Zone of claw | FV Zone of claw | RV Zone of claw | DF Zone of claw |
| Diagnosis | FV Diagnosis | RV Diagnosis | DF Diagnosis |
| Treatment | FV Treatment | RV Treatment | DF Treatment |
| LCS | FV LCS | RV LCS | DF LCS |
| Lesion severity | FV Lesion severity | RV Lesion severity | DF Lesion severity |

LCS: locomotion score, FV: farm veterinarian, RV: remote veterinarian, DF: dairy farmer.

Table 4-2: An example of the presentation of data in the Microsoft excel spreadsheet provided for the study, as recorded by the FV. Each column consisted of a different rater specific variable and each row contained a unique lesion. Each variable used a unique numbering system to code for the different categories. The number of rows per cow for each lameness event was equal to the maximum number of lesions identified by any one rater. A second lameness event for one cow was recorded as a different date.

| Cow no. | Date of lameness event | FV Locomotion score | FV Limb & claw | FV Severity | FV Body region | FV Tissue | FV Diagnosis | FV Treatment |
|---|---|---|---|---|---|---|---|---|
| 367 | 8/8/2013 | 4 | 7 | 1 | 8 | 2 | 5 | 70 |
| 367 | 8/8/2013 | 4 | 5 | 2 | 10 | 7 | 5 | 70 |
| 367 | 8/8/2013 | 4 | 6 | 2 | 10 | 7 | 40 | 70 |
| 517 | 4/5/2013 | 4 | 5 | 2 | 8 | 1 | 23 | 70 |
| 517 | 4/5/2013 | Normal | Normal | Normal | Normal | Normal | Normal | Normal |
| 2118 | 2/8/2013 | 4 | 5 | 3 | 8 | 1 | 8 | 70 |
| 2118 | 8/12/2013 | 4 | 5 | 3 | 8 | 1 | 8 | 70 |

FV: Farm veterinarian.

### 4.2.10. Initial checking of data

These data were assessed for duplicate records of which none were found. Each record for each rater was checked to ensure a valid value had been input. No invalid values were found.

### 4.2.11. Data exclusions and development of new variables

For the variables FV limb and claw and DF limb and claw, a decision was made to only use the limb. This was because where interdigital lesions were selected as the diagnosis, it was not possible to determine how the raters selected the affected claw (i.e., their selection may have been random rather than an informed decision). Therefore, two new variables, FV limb and DF limb were created. Each variable consisted of four categories (left fore, right fore, left hind or right hind limb).

The variable zone of claw was not considered in the analysis due to the potential challenges of one diagnosis affecting multiple zones and uncertainty regarding how the zone was selected by raters, as detailed in Section 4.2.3. Further, feedback from the RV indicated that zones six and eight overlap; therefore, providing two options for the raters and potential for lack of consistency in their selection.

The limb was not matched between the FV and DF in two lameness events affecting two different cows. For the lameness event for the first cow, three lesions were identified by both observers. The FV identified all three lesions on the right hind limb; however, the DF identified two lesions on the right hind limb and one lesion on the left hind limb. For this lesion, as there was disagreement regarding the affected limb, it was excluded from certain stages of the data analysis between the FV and DF, but not between the FV and

RV (detailed in section 4.2.12). For the lameness event for the second cow, one lesion was identified by each rater. While the FV identified a lesion to be on the right hind limb, the DF identified a lesion on the left hind limb. These data were excluded from certain stages of the data analysis between the FV and DF, but not between the FV and RV (detailed in section 4.2.12). Because there were no other lesions recorded for this cow, the entire lameness event was removed. However, this did not involve removal of a cow from the dataset as this was the second lameness event for this particular cow.

Each lesion recorded by each rater was checked to determine the consistency of responses (e.g., did it make sense that the lesion identified by the rater was recorded in the body region or tissue reported by the rater?). Two lesions from one cow were excluded from certain stages of the data analysis between all observer pairings (detailed in section 4.2.12), because each rater identified a foot lesion to be associated with the tibia. Although all three raters reported this, from a clinical perspective this does not make sense without the provision of further information.

### 4.2.12. Variable aggregation and development of new variables

A decision was made to conduct the data analysis at the lameness event level for all variables for the following reasons: i) where there was more than one lesion recorded in a lameness event it was not possible to match lesion for lesion between raters (i.e., it was not possible to determine if the raters were referring to the same lesion); ii) as discussed in section 4.2.3, where a lesion may have been confluent over multiple zones, it is unclear whether raters treated this as multiple lesions or a single lesion; and, iii) for the sake of keeping all analysis consistent (only four cows had two limbs identified in a lameness event, therefore it was considered unnecessary to conduct the analysis at the limb level).

In the original dataset, each lesion recorded by each rater had an individual severity score. To conduct the analysis at the lameness event level, for each rater, where there was more than one lesion in a lameness event, only the most extreme severity score for any lesion identified in that lameness event was used. Therefore, three new variables were created at the lameness event level: FV maximum severity, RV maximum severity and DF maximum severity. These variables replaced FV lesion severity, RV lesion severity and DF lesion severity, respectively.

Other variables that were aggregated to the lameness event level prior to analysis were the rater specific variables for diagnosis and treatment. The categories of these variables were aggregated into groups because the DF had fewer categories available to choose from than the veterinarians. For diagnosis, the new variables were FV diagnosis aggregated, RV diagnosis aggregated and DF diagnosis aggregated. These variables replaced FV diagnosis, RV diagnosis and DF diagnosis, respectively. The groups were based on five broad regions of lesion location that were already defined by the lameness data capture form. Only categories that were selected by one or more raters were included in these groups (Table 4-3). For treatment, the new variables were FV treatment aggregated, RV treatment aggregated and DF treatment aggregated. These variables replaced FV treatment, RV treatment and DF treatment respectively. Only categories that were selected by one or more raters were included, defining six groups (Table 4-4). Because some of the original treatment categories were combination treatments (e.g., pain management, trim and antibiotic), each component of these combinations were segregated accordingly into the groups so that there were no longer combination categories. Therefore, at the lameness event level, each lameness event could have multiple treatments per rater.

### 4.2.13. Working data sets

After applying the exclusions and defining new variables as described in Sections 4.2.10 and 4.2.11, two working data sets were produced: one for each pair of raters to account for the different data exclusions between the two pairs of raters. How these data exclusions applied and what variables were included between each pair are described below.

#### *Farm veterinarian and dairy farmer*

The variables where agreement was assessed between the FV and DF were LCS, limb affected, maximum lesion severity, body region, tissue, diagnosis aggregated and treatment aggregated (Figure 4-3). This dataset started with 73 lameness events from 69 cows with 148 and 121 lesions identified by the FV and DF, respectively. The first variables assessed were FV and DF LCS and FV and DF limb affected, where no data exclusions applied. After the variables FV and DF limb affected, data exclusions were made where the limb was not matched between observers, and where there were inconsistencies in observer responses, as discussed in section 4.2.10. This resulted in 72 lameness events eligible for analysis for the remaining variables, consisting of 144 and 118 lesions identified by the FV and DF, respectively.

Table 4-3: Aggregation of categories into groups for the variables FV diagnosis aggregated, RV diagnosis aggregated and DF diagnosis aggregated.

| |
|---|
| Group 1: Lesions of the sole |
| Haemorrhage of sole |
| Sole ulcer |
| White line disease |
| Heel erosion |
| Bruised sole |
| Double sole |
| Sole trauma |
| Sole abscess |
| Group 2: Interdigital lesions |
| Foot rot |
| Interdigital dermatitis |
| Foreign body |
| Group 3: Digital lesions |
| Digital dermatitis |
| Septic Arthritis |
| Retroartic abscess |
| Group 4: Fissures of the claw wall |
| Horizontal groove |
| Group 5: Abnormalities of the wall |
| Normal overgrowth |
| Corkscrew claw |

Table 4-4: Aggregation of categories into groups for the variables FV treatment aggregated, RV treatment aggregated and FV treatment aggregated.

| |
|---|
| Group 1: Topical therapy only |
| Topical |
| Group 2: Systemic antibiotic |
| Oxytetracycline |
| Penicillin |
| Antibiotic |
| Group 3: Pain relief |
| Pain management |
| Group 4: Hoof trim |
| Hoof trim |
| Group 5: Block/lift |
| Block/lift |
| Group 6: Surgery |
| Amputation |
| Resection |
| Veterinarian |

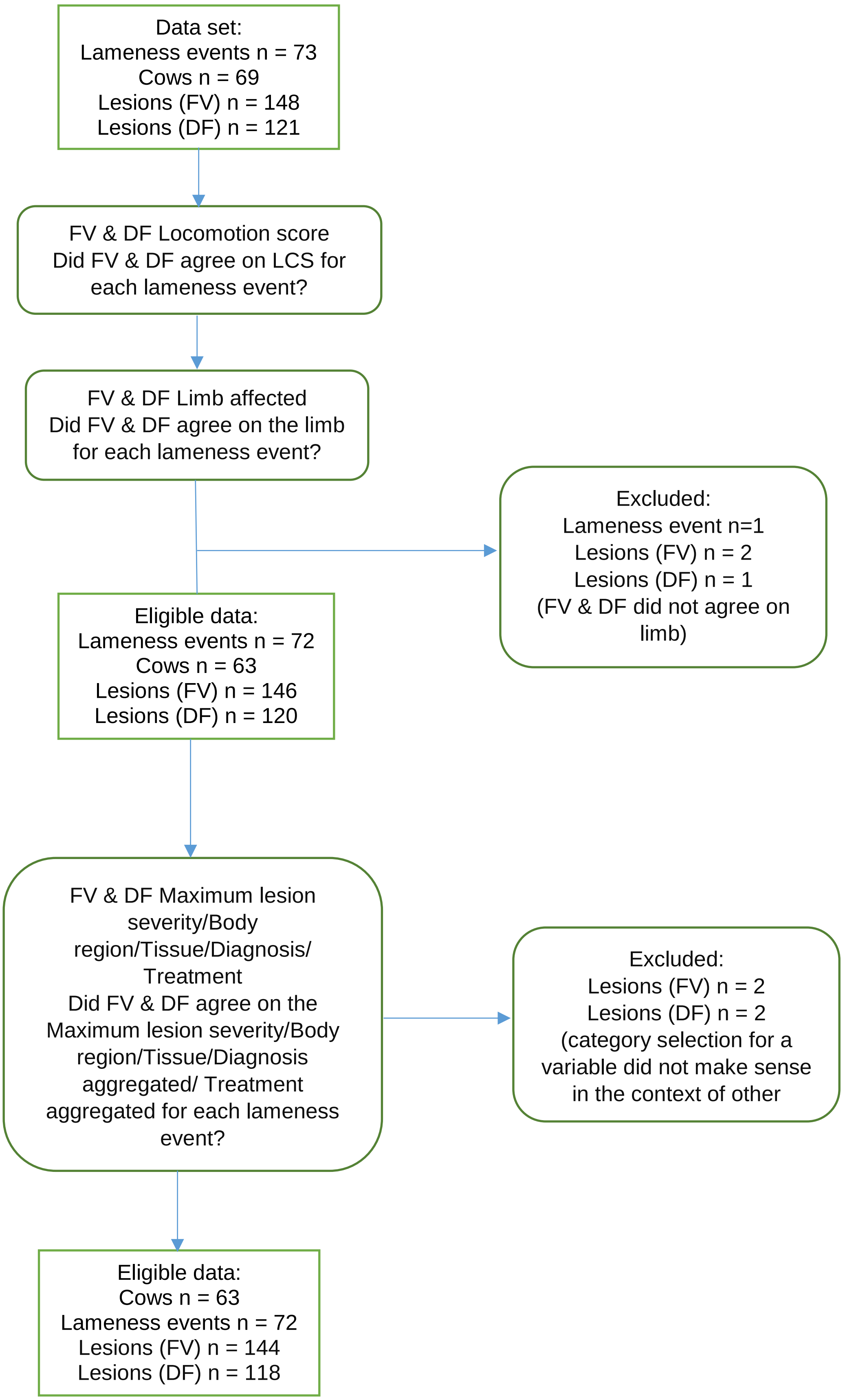


Figure 4-3: Flow diagram of the variables and eligible data included in the agreement analysis between the farm veterinarian (FV) and the dairy farmer (DF).

### *Farm veterinarian and remote veterinarian*

The variables assessed between the FV and RV were lesion severity, body region, tissue, diagnosis and treatment (Figure 4-4). This dataset started with 73 lameness events from 69 cows with 148 and 151 lesions identified by the FV and RV, respectively. Data exclusions were made where there were inconsistencies in rater responses, as discussed in section 4.2.10. This resulted in 73 lameness events eligible for analysis for all variables, consisting of 146 and 149 lesions identified by the FV and RV, respectively.

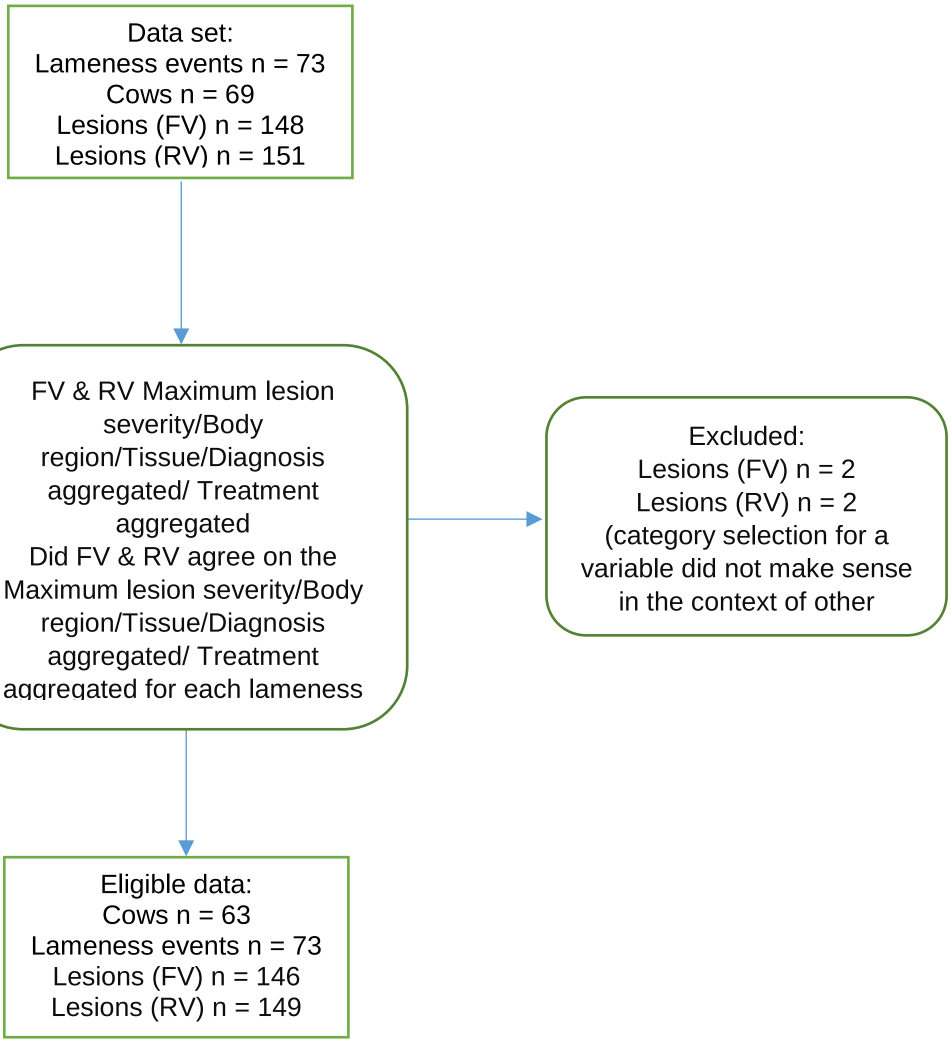


Figure 4-4: Flow diagram of the variables and eligible data included in the agreement analysis between the farm veterinarian (FV) and remote veterinarian (RV).

## 4.2.14. Data preparation for analysis

To conduct the analysis at the lameness event level it was necessary to prepare the data in the following way. For each nominal variable, for each pair of raters, a separate Microsoft excel® sheet was prepared. Each rater had a column for each category of the variable. The same category for each rater was placed side-by-side. For example, for the variable diagnosis for the rater pair FV-RV the columns were: FV lesions of the sole, RV lesions of the sole, FV interdigital lesions, RV interdigital lesions, FV digital lesions, RV digital lesions, FV fissures of the claw, RV fissures of the claw, FV abnormalities of the wall, RV abnormalities of the wall, FV lesions of the proximal limb and RV lesions of the proximal limb. For each lameness event for each cow, lesions were aggregated so that there was only one row per cow per lameness event. Therefore, a cow would only have more than one row if it had a second lameness event.

For each lameness event, data were prepared using the same underlying question which was asked for each rater of the pair, for each possible category of the variable in question (Table 4-5). For example, for the variable diagnosis, the question proposed was: for this lameness event, did the FV diagnose a lesion of the sole? The categories were marked as 0 if the rater did not select a lesion of the sole or 1 if the rater did select a lesion of the sole in that lameness event. This question was then repeated for the RV. This process was repeated for the remaining categories for each rater in each pair for each variable.

Because the lesions per lameness event were aggregated, a rater may have multiple categories selected per row (i.e., there may be more than one diagnosis per rater per lameness event. However, this did not necessary equate to the number of lesions identified by a rater as two different lesions may have been designated the same diagnosis).

Using the same three cows as rated by the FV from the example in Section 4.2.8, Table 4-6 demonstrates that cow 367 had a single lameness event with two diagnoses made by the FV (i.e., both lesions of the sole and abnormalities of the wall are marked as 1). Although the FV noted three lesions for this cow in this lameness event, two lesions had the same diagnosis. Cow 517 had one lameness event and one diagnosis as per FV. Cow 2188 has two lameness events, each with a single diagnosis made by the FV.

Table 4-5: Underlying question proposed for each variable for data preparation. The question was proposed for each category of each variable.

| Variable | Underlying question proposed for data preparation | Categories |
|---|---|---|
| Limb affected | 'For this lameness event did the rater observe that there was a lesion present on limb x?' | Left fore, right for, left hind, right hind. |
| Body region | 'For this lameness event did the rater observe that body region x was affected?' | Distal phalanx, intermediate phalanx, distal sesamoid, interdigital. |
| Tissue | 'For this lameness event did the rater observe that tissue x was affected?' | Hoof sole, hoof wall, hoof heel, skin, interdigital |
| Diagnosis aggregated | 'For this lameness event did the rater diagnose diagnosis x?' | Lesions of the sole, interdigital lesions, digital lesions, fissures of the claw, abnormalities of the wall, lesions of the proximal limb[1]. |
| Treatment aggregated | 'For this lameness event did the rater choose treatment x?' | Topical treatment only, systemic antibiotic, pain relief, hoof trim, block/lift, surgery. |

[1] This category was not assessed between the FV and DF.

Table 4-6: An example of how data were prepared for statistical analysis. For each nominal variable, for each pair of raters, a separate Microsoft excel sheet was prepared. Each rater had a column for each category of the variable. The same category for each rater was placed side-by-side (for the purpose of brevity, only the FV is shown in this example). For each lameness event for each cow, lesions were aggregated so that there was only one row per cow. Therefore, a cow would only have more than one row if it had a second lameness event. Using the variable diagnosis aggregated as an example, the categories were marked as 0 if the rater did not select the category in question or 1 if the rater did select the category in question for that lameness event.

| Cow no. | Date of lameness event | FV Lesions of the sole | FV Interdigital lesions | FV Digital lesions | FV Fissures of the claw wall | FV Abnormalities of the wall | FV Lesions of the proximal limb |
|---|---|---|---|---|---|---|---|
| 367 | 8/8/2013 | 1 | 0 | 0 | 0 | 1 | 0 |
| 517 | 4/5/2013 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2118 | 2/8/2013 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2118 | 8/12/2013 | 1 | 0 | 0 | 0 | 0 | 0 |

For the variable treatment aggregated, data were prepared in the same manner using the underlying question 'for this lameness event did the rater choose topical therapy only?' This was repeated for all available categories. Where a rater had selected a combination treatment from the original list of treatment options, all components for that rater were marked as 1. For example, for cow 245 the FV selected the treatment option pain management, trim and antibiotic; therefore, the categories systemic antibiotic, pain relief and hoof trim were all selected (Table 4-7).

Table 4-7: An example of the preparation of data for the variable treatment aggregated where a rater had selected a combination treatment. Using the FV selection as an example, all components of the treatment were marked as 1.

| Cow no. | Date of lameness event | FV Topical therapy only | FV Systemic antibiotic | FV Pain relief | FV Hoof trim | FV Block/lift | FV Surgery |
|---|---|---|---|---|---|---|---|
| 245 | 2/8/2013 | 0 | 1 | 1 | 1 | 0 | 0 |

For the ordinal variables (LCS and maximum lesion severity) it was not necessary to prepare the data in this way as there was only one category selected for each lameness event.

### 4.2.15. Statistical analysis

For each variable included in each data set, pairwise comparisons were made to assess the inter-rater agreement between the FV and DF and the FV and RV (Figure 4-5).

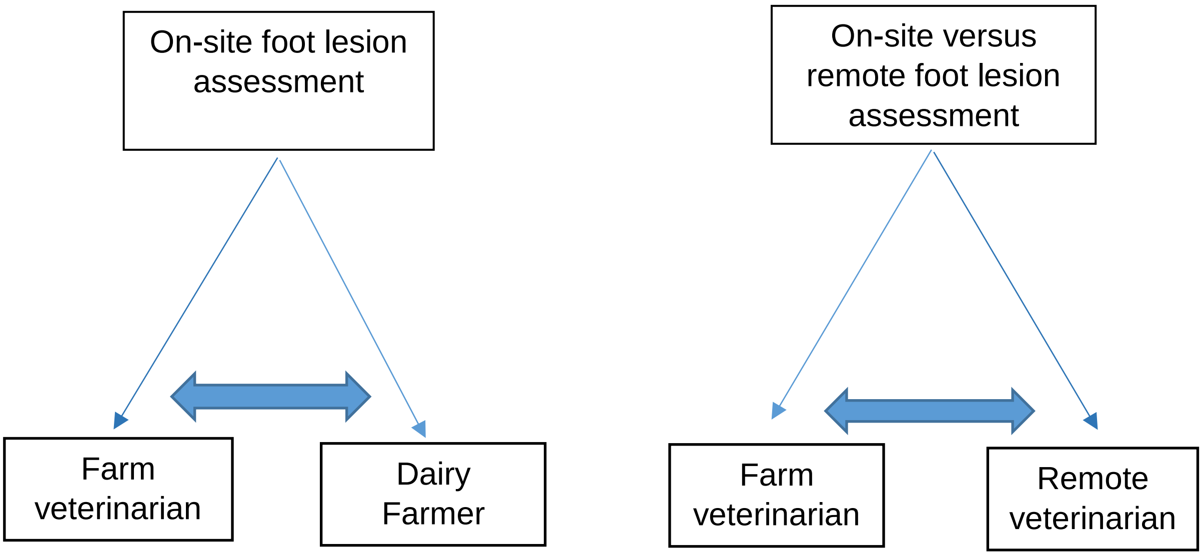


Figure 4-5: Pairwise comparisons were made to assess the inter-rater agreement between the farm veterinarian (FV) and the dairy farmer (DF) and the farm veterinarian and the remote veterinarian (RV).

#### *Nominal data*

Nominal variables were analysed using component dichotomy analysis as described in Chapter 2 Section 2.3.2. Using component dichotomy analysis each category of the variable in question was independently tested against all the other categories combined in a 2 x 2 matrix using the underlying questions proposed in Table 4-8. Therefore, for each category of the variables FV-DF limb affected, FV-DF and FV-RV body region, FV-DF and FV-RV tissue, FV-DF and FV-RV diagnosis aggregated and FV-DF and FV-RV treatment aggregated, results were summarised as a 2 x 2 matrix (Figure 4-6) using the notation in Table 4-9, resulting in several 2 x 2 matrices.

Inter-rater agreement was quantified for each 2 x 2 matrix using: proportion of overall agreement ($p_o$), alongside percent positive agreement (Ppos) and percent negative agreement (Pneg); and Cohens kappa coefficient (*k)*, alongside maximum kappa, and prevalence and bias indices (PI and BI, respectively). Estimates for $p_o$ were interpreted according to (Burn & Weir 2011) where $p_o \geq 75\%$ suggests substantial agreement. Estimates for *k* were interpreted using the guidelines of (McHugh 2012) where: 0 - 0.20 = none, 0.21 - 0.39 = minimal, 0.40 - 0.59 = weak, 0.60 – 0.79 = moderate, 0.80 – 0.90 = strong and, 0.91 – 1 = almost perfect. Values of 0.60 and above were considered to be clinically useful (McHugh 2012). The PI was interpreted as: 0 indicates a completely balanced population (i.e., 50% of agreements fall into one category and 50% in the other category) while an index of 1 suggests a homogenous population in which only one of the categories is represented (i.e., all agreements fall into one category). A PI ≤25% was considered well-balanced. The BI was interpreted as: 0 suggests no bias while a BI of 1 indicates complete bias. A BI ≤25% was considered minimal bias.

For each component dichotomy, the results were classified according to (Burn & Weir 2010) as follows: i) Both $p_o$ and *k* are high, exceeding the stated thresholds. The results are clinically useful and observers have met the criterion for adequate agreement. ii) $p_o$ falls below the set threshold, showing lack of agreement between observers. Following up with *k* is valid but unnecessary as *k* will be correspondingly low (i.e., observers demonstrate poor agreement). iii) $p_o$ exceeds the given threshold but *k* falls below it. These results are inconclusive (unclear), since the PI was too large. There is ambiguity due to an imbalance in the study population.

Overall proportional agreement and *k* were calculated using Stata® version 14.1. All other statistics were calculated using Winpepi version 11.44.

Table 4-8: Underlying question proposed for data analysis for each nominal variable. The question was proposed for each category of each variable.

| Variable | Underlying question proposed for data analysis | Categories |
|---|---|---|
| Limb affected | 'For this lameness event, did rater 1 and rater 2 agree that there was a lesion present on limb x?' | Left fore, right for, left hind, right hind. |
| FV-DF & FV-RV Body region | 'For this lameness event, did rater 1 and rater 2 agree that body region x was affected?' | Distal phalanx, intermediate phalanx, distal sesamoid, interdigital. |
| FV-DF & FV-RV | 'For this lameness event, did rater 1 and rater 2 agree that tissue x was affected?' | Hoof sole, hoof wall, hoof heel, skin, interdigital |
| Diagnosis aggregated | 'For this lameness event, did rater 1 and rater 2 agree that x was diagnosed?' | Lesions of the sole, interdigital lesions, digital lesions, fissures of the claw, abnormalities of the wall, lesions of the proximal limb[1]. |
| FV-DF & FV-RV Treatment aggregated | 'For this lameness event, did rater 1 and rater 2 agree that x treatment was given?' | Topical treatment only, systemic antibiotic, pain relief, hoof trim, block/lift, surgery. |

[1] This category was not assessed between the FV-DF.

| | | Rater 2 | | |
|---|---|---|---|---|
| | | No | Yes | Total |
| Rater 1 | No | A | B | n1 |
| | Yes | C | D | n2 |
| | Total | m1 | m2 | N |

Figure 4-6: For each category of a variable, results were summarised in a 2 x 2 matrix using the notation as described in Table 7.

Table 4-9: The notation used to complete the 2 x 2 matrices from the responses reported by two raters.

| | |
|---|---|
| A | Both rater 1 and rater 2 agreed that it was not the specific limb, body region, tissue, diagnosis, or treatment in question. |
| B | Rater 1 stated that it was not the specific limb, body region, tissue, diagnosis, or treatment in question. Rater 2 stated that it was the specific limb, body region, tissue, diagnosis, or treatment in question. |
| C | Rater 1 stated that it was the specific limb, body region, tissue, diagnosis, or treatment in question. Rater 2 stated that it was not the specific limb, body region, tissue, diagnosis, or treatment in question. |
| D | Both rater 1 and rater 2 stated that it was the specific limb, body region, tissue, diagnosis, or treatment in question. |
| n1 | Total number of lameness events where rater 1 stated that it was not the specific limb, body region, tissue, diagnosis, or treatment in question. |
| n2 | Total number of lameness events where rater 1 stated that it was the specific limb, body region, tissue, classification, diagnosis, or treatment in question. |
| m1 | Total number of lameness events where rater 2 stated that it was not the specific limb, body region, tissue, diagnosis, or treatment in question. |
| m2 | Total number of lameness events where rater 2 stated that it was the specific limb, body region, tissue, diagnosis, or treatment in question. |
| N | Total number of lameness events included in the analysis. |

#### *Ordinal data*

For the variable LCS a 5 x 5 matrix was created for the FV-DF pair. For lesion severity, a 4 x 4 matrix was created for each pair of raters. Inter-rater agreement was quantified using $p_o$ and weighted kappa (*wk)* applying linear weighting using Stata® version 14.1. Because the calculation of $p_o$ is influenced by the number of categories available for a variable (expected $p_o$ reduces as the number of possible categories increases), the 75% limit was not used for these data (Burn et al. 2009). Estimates for *wk* were interpreted as described for *k*. The PI can only be used with binary data and was therefore inappropriate for these data (Burn et al. 2009).

## 4.3. Results

### 4.3.1. Study population

The study population consisted of 259 dairy cows. Data on cow age, parity number and breed were missing for 24 lame cows; therefore, the following summaries include 235 dairy cows in total (this includes 45 lame dairy cows). The mean age for all cows and non-lame cows was 4.4 years (range: 2 - 13) while the mean age of lame cows was 4.3 (range:

2 - 11) (Table 4-10). The mean parity of all cows and non-lame cows was 2.5 (range: 1 - 8), while the mean parity of lame cows was 2.6 (range: 1 - 8). Most of the herd were Holstein Friesian dairy cows (n = 183, including 34 lame cows) (Table 4-11).

Table 4-10: Summary of 235 dairy cows lame by age and parity number, including 45 lame cows and 190 non-lame cows, during the study period 21 January - 31 December 2013.

| Variable | Mean (SD) | Median (IQR) | Range |
|---|---|---|---|
| Age | | | |
| All cows | 4.4 (2.2) | 4 (3, 6) | 2 – 13 |
| Non-lame cows | 4.4 (2.2) | 4 (3, 6) | 2 – 13 |
| Lame cows | 4.3 (2.4) | 3 (2, 5) | 2 – 11 |
| Parity | | | |
| All cows | 2.5 (1.6) | 2 (1, 3) | 1 – 8 |
| Non-lame cows | 2.5 (1.6) | 2 (1, 3) | 1 – 8 |
| Lame cows | 2.5 (1.8) | 2 (2, 4) | 1 – 8 |

SD: standard deviation, IQR: interquartile range.

Table 4-11: Summary of 235 dairy cows lame by breed, including 45 lame cows and 190 non-lame cows, during the study period 21 January - 31 December 2013.

| Breed | Total cows (%) | Non-lame cows (%) | Lame cows (%) |
|---|---|---|---|
| Holstein Friesian | 183 (78) | 149 (78) | 34 (76) |
| Jersey | 1 (0.5) | 1 (0.5) | 0 |
| Brown Swiss | 6 (3) | 6 (3) | 0 |
| Crossbreed | 45 (19) | 34 (18) | 11 (24) |
| Total | 235 (100) | 190 (100) | 45 (100) |

Data from a further 21 lame cows were missing for calving dates. Therefore, data were available for calculating days from calving to lameness for only 24 lame cows; six of these cows were lame prior to calving. The mean number of days from calving to lameness was 88 days (range 81 – 269 days).

Nine cows were excluded from the summary of the lactation data because no values were reported, leaving 226 cows (43 lame cows and 183 non-lame cows). The mean milk yield, protein content and fat content for these cows, non-lame cows and lame cows are reported in Table 4-12.

Table 4-12: Summary statistics of lactation data including milk yield, milk protein content and milk fat content in litres (L) per cow for the lactation during the study period, 21 January - 31 December 2013, for 226 cows, including 43 lame cows and 183 non-lame cows.

| Lactation parameters | Mean (SD) | Median | Range |
|---|---|---|---|
| Milk Yield (L) | | | |
| All cows | 7,322 (3,189) | 7,593 (5,421 – 8,822) | 110 - 17,435 |
| Non-lame cows | 7,334 (3,249) | 7,534 (5,456 – 8,772) | 110 - 17,435 |
| Lame cows | 7,258 (2,998) | 7,694 (5,169 – 9, 107) | 148 - 13,573 |
| Milk Protein (L) | | | |
| All cows | 233 (104) | 234 (172 – 280) | 5 – 570 |
| Non-lame cows | 234 (105) | 233 (173 – 283) | 5 – 570 |
| Lame cows | 226 (96) | 241 (171 – 275) | 5 – 444 |
| Milk Fat (L) | | | |
| All cows | 283 (131) | 289 (203 - 348) | 6 – 775 |
| Non-lame cows | 285 (133) | 285 (203 – 352) | 6 – 775 |
| Lame cows | 274 (121) | 274 (203 – 343) | 6 – 548 |

SD: standard deviation.

### 4.3.2. Lameness event data

A total of 73 lameness events were recorded from 69 cows: 66 cows having a single lameness event, two cows having two lameness events and one cow having three lameness events. For each lameness event, the FV identified 69 events as affecting a single limb only and four events affecting two limbs. The DF identified 68 events as affecting a single limb only and five events affecting two limbs. From the 73 lameness events the FV identified 148 lesions, the RV 151 lesions, and the DF 121 lesions (Table 4-13). Half (51%) of the lameness events were reported in the winter period (June - August) (Table 4-14).

For LCS, scores 4 and 3 were the most frequently reported scores by both the FV and DF (Table 4-15); the majority of lameness events were found in the left or right hind limbs by both FV and DF (Table 4-16); the most frequently reported maximum lesion severity scores were 2 and 3 by the FV and RV while the DF most frequently reported scores 1 and 2 (Table 4-17); distal phalanx and interdigital were the most frequently reported body regions by all raters (Table 4-18); skin and hoof sole were the most frequently reported tissue by all raters (Table 4-19); lesions of the sole and interdigital lesions were the most frequently recorded lesions for diagnosis by all raters (Table 4-20); and, topical therapy and hoof trim were the most frequently recorded treatments by all raters (Table 4-21).

Table 4-13: Number of lesions identified by the farm veterinarian, remote veterinarian and the dairy farmer from 73 lameness events.

| | Farm veterinarian | | Remote veterinarian | | Dairy farmer | |
|---|---|---|---|---|---|---|
| Number of lesions in a lameness event | Frequency of number of lesions | Total number of lesions | Frequency of number of lesions | Total number of lesions | Frequency of number of lesions | Total number of lesions |
| 0 | 0 | 0 | 0 | 0 | 7 | 0 |
| 1 | 23 | 23 | 21 | 21 | 26 | 26 |
| 2 | 35 | 70 | 36 | 72 | 36 | 72 |
| 3 | 5 | 15 | 6 | 18 | 0 | 0 |
| 4 | 10 | 40 | 10 | 40 | 4 | 16 |
| Total | 73 | 148 | 73 | 151 | 73 | 114 |

Table 4-14: Frequency table of the number of lameness events (n = 73) each season.

| Season | No of lameness events (% of lameness events) |
|---|---|
| Summer | 16 (22) |
| Autumn | 12 (16) |
| Winter | 37 (51) |
| Spring | 8 (11) |

Table 4-15: Frequency table for locomotion score for the 73 lameness events involving 69 dairy cows as determined by the farm veterinarian and dairy farmer.

| Locomotion Score | Farm Veterinarian (% of lameness events) | Dairy Farmer (% of lameness events) |
|---|---|---|
| 1 | 1 (1) | 10 (14) |
| 2 | 6 (8) | 11 (15) |
| 3 | 29 (40) | 22 (30) |
| 4 | 35 (48) | 27 (37) |
| 5 | 2 (3) | 3 (4) |

Table 4-16: Frequency table for limb affected as determined by the farm veterinarian and dairy farmer for 73 lameness events.

| Limb | Farm veterinarian (% of limbs affected) | Dairy farmer (% of limbs affected) |
|---|---|---|
| Left fore | 3 (4) | 3 (4) |
| Right fore | 3 (4) | 3 (4) |
| Left hind | 35 (48) | 37 (51) |
| Right hind | 36 (49) | 35 (48) |

Table 4-17: Frequency table for maximum lesion severity for the two rater pairs: farm veterinarian and dairy farmer, including 72 lameness events; and farm veterinarian and remote veterinarian, including 73 lameness events.

| Severity score | Farm veterinarian (% of lameness events) | Dairy farmer (% of lameness events) |
|---|---|---|
| 1 | 5 (7) | 15 (21) |
| 2 | 23 (32) | 26 (36) |
| 3 | 29 (40) | 11 (15) |
| 4 | 15 (21) | 13 (18) |
| Severity score | Farm veterinarian (% of lameness events) | Remote veterinarian (% of lameness events) |
| 1 | 5 (7) | 10 (14) |
| 2 | 23 (32) | 33 (45) |
| 3 | 29 (40) | 21 (29) |
| 4 | 16 (22) | 9 (12) |

Table 4-18: Frequency table for body region for the two rater pairs: farm veterinarian and dairy farmer, including 72 lameness events; and farm veterinarian and remote veterinarian, including 73 lameness events.

| Body region | Farm veterinarian (% of lameness events) | Dairy farmer (% of lameness events) |
|---|---|---|
| Intermediate phalanx | 3 (4) | 3 (4) |
| Distal phalanx | 52 (71) | 48 (67) |
| Interdigital | 24 (33) | 18 (25) |
| Body region | Farm veterinarian (% of lameness events) | Remote veterinarian (% of lameness events) |
| Intermediate phalanx | 3 (4) | 3 (4) |
| Distal phalanx | 52 (71) | 60 (82) |
| Distal sesamoid | 0 (0) | 1 (1.4) |
| Interdigital | 24 (33) | 15 (21) |

Table 4-19: Frequency table for tissue for the two rater pairs: farm veterinarian and dairy farmer, including 72 lameness events; and farm veterinarian and remote veterinarian, including 73 lameness events.

| Tissue | Farm veterinarian (% of lameness events) | Dairy farmer (% of lameness events) |
|---|---|---|
| Hoof sole | 27 (38) | 25 (35) |
| Hoof wall | 7 (10) | 4 (6) |
| Hoof heel | 19 (26) | 13 (18) |
| Skin | 38 (52) | 31 (43) |
| Joint | 0 (0) | 1 (1.4) |
| Tissue | Farm veterinarian (% of lameness events) | Remote veterinarian (% of lameness events) |
| Hoof sole | 27 (38) | 35 (48) |
| Hoof wall | 7 (10) | 6 (8) |
| Hoof heel | 20 (27) | 33 (25) |
| Skin | 37 (51) | 33 (45) |
| Joint | 1 (1.4) | 1 (1.4) |

Table 4-20: Frequency table for diagnosis for the two rater pairs: farm veterinarian and dairy farmer, including 72 lameness events; and farm veterinarian and remote veterinarian, including 73 lameness events.

| Classification | Farm veterinarian (% of lameness events) | Dairy farmer (% of lameness events) |
|---|---|---|
| Lesions of the sole | 44 (61) | 36 (50) |
| Interdigital lesions | 36 (50) | 23 (32) |
| Digital lesions | 2 (3) | 1 (1.4) |
| Fissures of the claw | 9 (13) | 7 (10) |
| Abnormalities of the wall | 2 (3) | 5 (7) |
| **Classification** | **Farm veterinarian (% of lameness events)** | **Remote veterinarian (% of lameness events)** |
| Lesions of the sole | 44 (60) | 50 (68) |
| Interdigital lesions | 36 (50) | 30 (41) |
| Digital lesions | 2 (3) | 2 (3) |
| Fissures of the claw | 11 (15) | 7 (10) |
| Abnormalities of the wall | 2 (3) | 1 (1.4) |
| Lesions of the proximal limb | 0 (0) | 1 (1.4) |

Table 4-21: Frequency table for treatment for the two rater pairs: farm veterinarian and farm worker, including 72 lameness events; and farm veterinarian and remote veterinarian, including 73 lameness events.

| Treatment | Farm veterinarian (% of lameness events) | Dairy farmer (% of lameness events) |
|---|---|---|
| Topical therapy only | 40 (56) | 22 (31) |
| Systemic antibiotic | 2 (3) | 5 (7) |
| Pain relief | 10 (14) | 8 (11) |
| Hoof trim | 40 (56) | 32 (44) |
| Block/lift | 7 (10) | 4 (6) |
| Surgery | 4 (6) | 3 (4) |
| **Treatment** | **Farm veterinarian (% of lameness events)** | **Remote veterinarian (% of lameness events)** |
| Topical therapy only | 40 (56) | 46 (63) |
| Systemic antibiotic | 2 (3) | 1 (1.4) |
| Pain relief | 10 (14) | 11 (15) |
| Hoof trim | 40 (56) | 32 (44) |
| Block/lift | 7 (10) | 5 (7) |
| Surgery | 5 (7) | 5 (7) |

### 4.3.3. Inter-rater agreement

#### *Farm veterinarian and dairy farmer*

Table 4-22 presents the results of the agreement analysis with respect to the variables limb affected, body region, tissue, diagnosis aggregated and treatment aggregated. The 2 x 2 matrices for each category of each variable are presented in Appendix 12. Many prevalence indices were unbalanced with 14 of 24 (58%) categories having high prevalence indices (PI > 0.26). Taking *k* values above 0.60 to be clinically useful, half of these obtained clinically acceptable agreement ratings despite these unbalanced prevalence indices. The remaining half showed poor agreement as indicated by their *k* values, however they had high $p_o$, meaning that their interpretation is unclear. Ten categories had well balanced prevalence indices (PI ≤ 0.25). Seven of these exceeded the criterion for both $p_o$ and *k*, indicating clear agreement between the FV and DF while three of these categories attained genuinely poor agreement ($p_o$ below 75% and *k* values below 0.60). No variables demonstrated high bias indices. The results are summarised below for each variable.

### Limb affected

Proportion of overall agreement ranged from 97 to 100% and both PPos and PNeg were greater than 97% for all categories. Kappa and maximum *k* ranged from 0.95 to 1. Prevalence and bias indices for all categories were well below 50% indicating clear consistency between raters.

### Body region

Proportion of overall agreement ranged from 90 to 100% and both PPos and PNeg were greater than 85% for all categories. Kappa ranged from 0.77 to 1 with maximum *k* values ranging from 0.80 to 1. Distal phalanx and interdigital achieved clinically useful *k* values despite unbalanced prevalence indices (37.5% and 40%, respectively). Bias indices were low for all categories.

### Tissue

Proportion of overall agreement ranged from 89 to 99%. Percent positive agreement ranged from 55 to 99% while PNeg ranged from 0 to 96%. Kappa ranged from 0 to 0.82 with maximum *k* values ranging from 0 to 0.94. The PI of skin was well-balanced and both $p_o$ and *k* exceeded the set thresholds, indicating consistency between raters. The prevalence indices for hoof sole, hoof wall, hoof heel and joint were 27.8%, 84.7%, 55.6% and 98.6%, respectively. The level of agreement between raters regarding the selection of hoof sole and hoof heel was considered clinically useful despite the unbalanced PI as both $p_o$ and *k* values met the given thresholds. The level of agreement between raters for hoof wall and joint was inconclusive as $p_o$ exceeded the given threshold but *k* fell below it.

### Diagnosis

Proportion of overall agreement ranged from 71 to 99%. Percent positive agreement ranged from 0 to 75% while PNeg ranged from 69 to 99%. Kappa ranged from -0.02 to 0.66 with maximum *k* values ranging from 0.27 to 0.86. The prevalence indices for lesions of the sole and interdigital lesions were well-balanced (11.1 and 18.1, respectively), however, $p_o$ fell below the given threshold indicating lack of agreement between raters (72.2% and 70.8%, respectively). Kappa values were correspondingly low (0.44 and 0.42 respectively). The prevalence indices for digital lesions, fissures of the claw, abnormalities of the wall and lesions of the proximal limb were 95.8, 77.8, 90.3 and 62.5, respectively. The level of agreement between raters regarding the diagnosis of digital lesions was considered clinically useful despite the unbalanced PI. For the remaining categories, $p_o$ exceeded the given threshold, however, *k* did not. These results were inconclusive.

### Treatment

Proportion of overall agreement ranged from 72 to 96%. Percent positive agreement ranged from 29 to 81% while PNeg ranged from 76 to 81%. Kappa values ranged from 0.25 to 0.75 with maximum *k* values ranging from 0.52 to 0.87. The PI for trim was 0 and both $p_o$ and *k* exceeded the set thresholds, indicating consistency between raters. The PI for topical therapy was well-balanced PI (13.9), however, $p_o$ fell below the given threshold (72.2) indicating lack of agreement between raters; *k* was correspondingly low (0.47). The prevalence indices for systemic antibiotic, pain relief, block/lift and amputate/resection/veterinarian were 90.3, 75, 84.7 and 90.3 respectively. The level of agreement between raters regarding the selection of pain relief and block/lift were considered clinically useful despite the unbalanced prevalence indices. The level of agreement between raters for systemic antibiotic and amputate/resection/veterinarian was inconclusive as $p_o$ exceeded the given threshold but *k* fell below it.

### Locomotion score

Proportion of overall agreement was 85.27% and *k* was 0.44 (95%CI: 0.29 to 0.58). The 5 x 5 matrix for LCS is presented in Appendix 13.

### Maximum lesion severity

Proportion of overall agreement was 73.26% and *k* was 0.13 (95%CI: -0.02 to 0.28). The 4 x 4 matrix for maximum lesion severity is presented in Appendix 14.

### *Farm veterinarian and remote veterinarian*

Table 4-23 presents the results of the agreement analysis with respect to the variables body region, tissue, diagnosis aggregated and treatment aggregated. The 2 x 2 matrices for each category are presented in Appendix 15. Several prevalence indices were unbalanced with 14 of 21 (67%) categories having high prevalence indices. Nine of these were clinically useful despite having high prevalence indices. The remaining five showed poor agreement as indicated by their *k* values, however they had high $p_o$, meaning that their interpretation is unclear. Seven categories had well balanced prevalence indices below 0.25, exceeding the criterion for both $p_o$ and *k*, indicating clear agreement between the raters. No variables demonstrated high bias indices. The results are summarised below for each variable.

### Body region

Proportion of overall agreement ranged from 88 to 100%. Both PPos and PNeg were greater than 77% for all categories. Kappa and maximum *k* values ranged from 0 to 1. Intermediate phalanx had perfect agreement. The prevalence indices for distal phalanx, distal sesamoid and interdigital were 53.4%, 98.6 and 46.6%, respectively. The level of agreement between raters regarding the selection of distal phalanx and interdigital were clinically useful despite the unbalanced prevalence indices as both $p_o$ and k values met the given thresholds. The level of agreement between raters for distal sesamoid was inconclusive as $p_o$ exceeded the given threshold but *k* fell below it.

### Tissue

Proportion of overall agreement ranged from 89 to 100%. Both PPos and PNeg were greater than 77% for all categories. Kappa and maximum *k* values ranged from 0.72 to 1 and 0.81 to 1, respectively. The prevalence indices for hoof sole, skin and joint were well balanced and both $p_o$ and *k* exceeded the set thresholds, indicating consistency between raters. The prevalence indices for hoof wall and hoof heel were 82.2% and 47.9% respectively, however, because both $p_o$ and *k* exceeded the required thresholds they are considered clinically useful.

### Diagnosis

Proportion of overall agreement ranged from 84 to 99%. Percent positive agreement ranged from 0 to 87% while PNeg ranged from 77 to 99%. Kappa and maximum *k* values ranged from 0 to 0.73 and 0 to 1, respectively. The prevalence indices for lesions of the sole and interdigital lesions were well balanced and both $p_o$ and *k* exceeded the set thresholds indicating consistency between raters. The prevalence indices for digital lesions, fissures of the claw, abnormalities of the wall and lesions of the proximal limb were 94.5, 75.3, 98.6 and 98.6, respectively. While $p_o$ exceeded the given threshold for each of these categories, *k* did not. Therefore, these results were inconclusive.

### Treatment

Proportion of overall agreement ranged from 86 to 99%. Percent positive agreement ranged from 67 to 95% while PNeg ranged from 87 to 99%. Kappa and maximum *k* values ranged from 0.66 to 0.94 and 0.66 to 1, respectively. The prevalence indices for topical therapy and trim were well balanced and both po and *k* exceeded the set thresholds indicating consistency between raters. The prevalence indices for systemic antibiotic, pain relief, block/lift and amputate/resection/veterinarian were 95.9, 71.2, 83.6 and 86.3 respectively, however, because both $p_o$ and *k* exceeded the required thresholds, the results can be considered clinically useful.

### Maximum lesion severity

Proportion of overall agreement was 83.11% and *k* was 0.51 (95%CI: 0.35 to 0.66). The 4 x 4 matrix for maximum lesion severity is presented in Appendix 16.

## 4.3.1. Summary of results

Table 4-24 provides a summary of the inter-rater agreement results for each pair of raters using the classification outlined in Section 4.2.14. This table details whether the PI was balanced or unbalanced; if inter-rater agreement results were clinically useful or not; and, whether inter-rater agreement was adequate, unclear or poor.

Table 4-22: Results of the agreement analysis between the farm veterinarian and dairy farmer for limb affected, body region, tissue, diagnosis and treatment.

| Variable | $p_o$ | PPos | PNeg | Kappa (CI 95%) | Max. kappa | PI | BI |
|---|---|---|---|---|---|---|---|
| Limb affected | | | | | | | |
| Left fore | 100 | NC | NC | 1 (NC) | NC | NC | NC |
| Right fore | 100 | NC | NC | 1 (NC) | NC | NC | NC |
| Left hind | 97.3 | 97.2 | 97.3 | 0.95 (0.87 – 1) | 0.95 | 1.4 | 2.7 |
| Right hind | 98.6 | 98.6 | 98.7 | 0.97 (0.92 – 1) | 0.97 | 2.7 | 1.4 |
| Body region | | | | | | | |
| Intermediate phalanx | 100 | NC | NC | 1 (NC) | NC | NC | NC |
| Distal phalanx | 90.3 | 92.9 | 84.4 | 0.77 (0.62 – 0.93) | 0.90 | 37.5 | 4.2 |
| Interdigital | 91.7 | 85.7 | 93.9 | 0.8 (0.65 – 0.95) | 0.80 | 40 | 8.6 |
| Tissue | | | | | | | |
| Hoof sole | 91.7 | 88.5 | 93.5 | 0.82 (0.68 - 0.96) | 0.94 | 27.8 | 2.8 |
| Hoof wall | 93.1 | 54.5 | 96.2 | 0.51 (0.14 - 0.88) | 0.71 | 84.7 | 4.3 |
| Hoof heel | 88.9 | 75 | 92.9 | 0.68 (0.48 - 0.88) | 0.76 | 55.6 | 8.3 |
| Skin | 90.3 | 89.9 | 90.7 | 0.81 (0.67 - 0.94) | 0.81 | 4.2 | 9.7 |
| Joint | 98.6 | 99.3 | 0 | 0 (-0.01 - 0.81) | 0 | 98.6 | 1.4 |
| Diagnosis | | | | | | | |
| Lesions of the sole | 72.2 | 75 | 68.8 | 0.44 (0.24 - 0.65) | 0.78 | 11.1 | 11.1 |
| Interdigital lesions | 70.8 | 64.4 | 75.3 | 0.42 (0.22 - 0.61) | 0.64 | 18.1 | 18.1 |
| Digital lesions | 98.6 | 66.7 | 99.3 | 0.66 (0.04 – 1) | 0.66 | 95.8 | 1.4 |
| Fissures of the claw | 88.9 | 50 | 93.8 | 0.44 (0.11 - 0.76) | 0.86 | 77.8 | 2.8 |
| Abnormalities of the wall | 90.3 | 0 | 94.9 | -0.02 (-0.07 - 0.02) | 0.27 | 90.3 | 6.9 |
| Lesions of the proximal limb | 76.4 | 37 | 85.5 | 0.29 (0.08 - 0.50) | 0.29 | 62.5 | 23.6 |
| Treatment | | | | | | | |
| Topical therapy only | 72.2 | 67.7 | 75.6 | 0.47 (0.29 - 0.64) | 0.52 | 13.9 | 25 |
| Systemic antibiotic | 95.8 | 57.1 | 97.8 | 0.55 (0.11 - 1.00) | 0.55 | 90.3 | 4.2 |
| Pain relief | 94.4 | 77.8 | 96.8 | 0.75 (0.51 - 0.98) | 0.87 | 75 | 2.2 |
| Trim | 80.6 | 80.6 | 80.6 | 0.62 (0.44 - 0.79) | 0.78 | 0 | 11.1 |
| Block/lift | 95.8 | 72.7 | 97.7 | 0.71 (0.40 - 1.00) | 0.71 | 84.7 | 4.2 |
| Surgery | 93.1 | 28.6 | 96.4 | 0.25 (-0.20 - 0.70) | 0.85 | 90.3 | 1.4 |

$p_o$: proportion of overall agreement, PPos: percent positive agreement, PNeg: percent negative agreement, CI: confidence interval, Max. kappa: maximum kappa, PI: prevalence index, BI: bias index, NC: not calculated.

Table 4-23: Results of the agreement analysis between the farm veterinarian and remote veterinarian for limb affected, body region, tissue, diagnosis and treatment.

| Variable | $p_o$ | PPos | PNeg | Kappa (95% CI) | Max. kappa | PI | BI |
|---|---|---|---|---|---|---|---|
| Body region | | | | | | | |
| Intermediate phalanx | 100 | NC | NC | 1 (NC) | NC | NC | NC |
| Distal phalanx | 89.0 | 92.9 | 76.5 | 0.7 (0.51 - 0.89) | 0.7 | 53.4 | 11 |
| Distal sesamoid | 98.6 | 0 | 99.3 | 0 -0.01 - 0.81 | 0 | 98.6 | 1.4 |
| Interdigital | 87.7 | 76.9 | 91.6 | 0.69 0.51 - 0.87 | 0.69 | 46.6 | 12.3 |
| Tissue | | | | | | | |
| Hoof sole | 90.4 | 89.2 | 91.4 | 0.81 0.67 - 0.94 | 0.81 | 11 | 9.6 |
| Hoof wall | 95.9 | 76.9 | 97.7 | 0.75 0.47 – 1 | 0.92 | 82.2 | 1.4 |
| Hoof heel | 89 | 78.9 | 92.6 | 0.72 0.53 - 0.90 | 0.93 | 47.9 | 2.7 |
| Skin | 91.8 | 91.4 | 92.1 | 0.84 0.71 - 0.96 | 0.89 | 4.1 | 5.5 |
| Joint | 100 | NC | NC | 1 (NC) | NC | NC | NC |
| Diagnosis | | | | | | | |
| Lesions of then sole | 83.6 | 87.2 | 76.9 | 0.64 (0.46 - 0.82) | 0.82 | 28.8 | 8.2 |
| Interdigital lesions | 86.3 | 84.8 | 87.5 | 0.73 (0.57 - 0.88) | 0.84 | 9.6 | 8.2 |
| Digital lesions | 97.3 | 50 | 98.6 | 0.49 (-0.13 - 1.00) | 1 | 94.5 | 0 |
| Fissures of the claw | 89 | 55.6 | 93.8 | 0.5 (0.20 - 0.79) | 0.75 | 75.3 | 5.5 |
| Abnormalities of the wall | 98.6 | 0 | 99.3 | 0 (-0.01 - 0.81) | 0 | 98.6 | 1.4 |
| Lesions of the proximal limb | 98.6 | 0 | 99.3 | 0 (-0.01 - 0.82) | 0 | 98.6 | 1.4 |
| Treatment | | | | | | | |
| Topical therapy only | 89.0 | 90.7 | 86.7 | 0.78 (0.63 - 0.92) | 0.83 | 17.8 | 8.2 |
| Systemic antibiotic | 98.6 | 66.7 | 99.3 | 0.66 (0.04 - 1.00) | 0.66 | 95.9 | 1.4 |
| Pain relief | 98.6 | 95.2 | 99.2 | 0.94 (0.84 - 1.00) | 0.94 | 71.2 | 1.4 |
| Trim | 86.3 | 86.1 | 86.5 | 0.73 (0.58 - 0.88) | 0.78 | 1.4 | 11.1 |
| Block/lift | 97.3 | 83.3 | 98.5 | 0.82 (0.58 - 1.00) | 0.82 | 83.6 | 2.7 |
| Surgery | 97.3 | 80 | 98.5 | 0.79 (0.50 - 1.00) | 1 | 86.3 | 0 |

$p_o$: proportion of overall agreement, PPos: percent positive agreement, PNeg: percent negative agreement, CI: confidence interval, Max kappa: maximum kappa, PI: prevalence index, BI: bias index, NC: not calculated.

Table 4-24: Summary of inter-rater agreement results for each category of each variable for each pair of raters.

| | FV-DF | | | FV-RV | | |
|---|---|---|---|---|---|---|
| Variable | Prevalence index (Balanced/Unbalanced/ Unclear) | Clinically useful (Yes/No/Unclear) | Agreement (Adequate/Unclear/ Poor) | Prevalence index (Balanced/Unbalanced/ Unclear) | Clinically useful (Yes/No/Unclear) | Agreement (Adequate/Poor/Unclear) |
| Limb | | | | | | |
| Left fore | Balanced | Yes | Adequate | Not applicable | Not applicable | Not applicable |
| Right for | Balanced | Yes | Adequate | Not applicable | Not applicable | Not applicable |
| Left hind | Balanced | Yes | Adequate | Not applicable | Not applicable | Not applicable |
| Right hind | Balanced | Yes | Adequate | Not applicable | Not applicable | Not applicable |
| Body region | | | | | | |
| Intermediate phalanx | Balanced | Yes | Adequate | Balanced | Yes | Adequate |
| Distal phalanx | Unbalanced | Yes | Adequate | Unbalanced | Yes | Adequate |
| Distal sesamoid | Not applicable | Not applicable | Not applicable | Unbalanced | Unclear | Unclear |
| Interdigital | Unbalanced | Yes | Adequate | Unbalanced | Yes | Adequate |
| Tissue | | | | | | |
| Hoof sole | Unbalanced | Yes | Adequate | Balanced | Yes | Adequate |
| Hoof wall | Unbalanced | Unclear | Unclear | Unbalanced | Yes | Adequate |
| Hoof heel | Unbalanced | Yes | Adequate | Unbalanced | Yes | Adequate |
| Skin | Balanced | Yes | Adequate | Balanced | Yes | Adequate |
| Joint | Unbalanced | Unclear | Unclear | Balance | Yes | Adequate |
| Diagnosis | | | | | | |
| Lesions of then sole | Balanced | Yes | Poor | Balanced | Yes | Adequate |
| Interdigital lesions | Balanced | Yes | Poor | Balanced | Yes | Adequate |
| Digital lesions | Unbalanced | Yes | Adequate | Unclear | Unclear | Unclear |
| Fissures of the claw | Unbalanced | Unclear | Unclear | Unclear | Unclear | Unclear |
| Abnormalities of the wall | Unbalanced | Unclear | Unclear | Unclear | Unclear | Unclear |

| | | | | | | |
|---|---|---|---|---|---|---|
| Lesions of proximal limb | Unbalanced | Unclear | Unclear | Unclear | Unclear | Unclear |
| Treatment | | | | | | |
| Topical therapy only | Balanced | Yes | Poor | Balanced | Yes | Adequate |
| Systemic antibiotic | Unbalanced | Unclear | Unclear | Unbalanced | Yes | Adequate |
| Pain relief | Unbalanced | Yes | Adequate | Unbalanced | Yes | Adequate |
| Trim | Balanced | Yes | Adequate | Balanced | Yes | Adequate |
| Block/lift | Unbalanced | Yes | Adequate | Unbalanced | Yes | Adequate |
| Surgery | Unbalanced | Unclear | Unclear | Unbalanced | Yes | Adequate |

## 4.4. Discussion

Overall, the FV-DF pair demonstrated poor to almost perfect agreement while the FV-RV pair demonstrated moderate to almost perfect agreement. There were a number of limitations identified in this study. These are discussed below following a discussion of the results of inter-rater agreement between each rater pair.

### 4.4.1. Inter-rater agreement

For most categories within most variables, it was possible to determine whether agreement between raters was clinically useful or not. In other cases, the level of agreement remained inconclusive as it was not possible to determine whether agreement really was poor, or whether chance agreement was too high, preventing the true extent of agreement to be determined (Hoehler 2000). These categories represent those occurring at a low prevalence in the study population (e.g., the category fissures of the claw for diagnosis). While the imbalance in prevalences is a limitation in terms of the overall assessment of agreement, the implications for judging the level of agreement between raters are discussed below.

#### *Farm veterinarian and dairy farmer*

For limb affected, body region and tissue, the FV-DF pair demonstrated almost perfect, moderate to almost perfect and moderate to strong agreement, respectively. This suggests that in most cases the raters were able to agree on the location of the lesions. While perfect agreement was not achieved for limb affected, this may be due to the occurrence of bilateral lesions which could potentially complicate identification of which limb was responsible for the lameness.

For diagnosis and treatment, the pair demonstrated weak to moderate agreement, indicating that there were differences in opinion for the diagnosis and how to treat the lame cows. For diagnosis it was possible to quantify the level of agreement for lesions of the sole, interdigital and digital lesions. The major concern here is that the two most prevalent lesions in this herd, lesions of the sole and interdigital lesions, only achieved weak levels of agreement. The maximum attainable $k$ for these categories remained below 0.80, indicating that $k$ could not reach the ‘‘strong or near perfect agreement’’ range, despite the low prevalence indices obtained. Where the FV diagnosed lesions of the sole, the DF reported interdigital lesions (n = 8), abnormalities of the wall (n = 4), fissures of the claw (n = 3), digital lesions (n = 1), or no lesion (n = 19). Where the FV diagnosed interdigital lesions, the DF reported lesions of the sole (n = 16), abnormalities of the wall (n = 3), fissures of the claw (n = 2), or no lesion (n = 12). The lack of consistency in the responses provided by the DF may be indicative of the limited ability of the DF to diagnose these particular lesions. Given that lesions of the sole and interdigital lesions were common in this herd (assuming correct diagnosis by the FV), this suggests that these lesions may frequently be misclassified by the dairy farmer, increasing the risk of probability for incorrect treatment. This has potentially been the case in this study as the level of agreement between the FV-DF for treatment was correspondingly weak to moderate.

For treatment, it was possible to quantify the level of agreement for topical therapy, pain relief, trim and block/lift. While the agreement for pain relief, trim and block/lift was moderate, agreement for topical therapy was weak. Given that topical therapy was one of the more common suggested treatments by all raters in this study it is concerning that agreement between raters was not higher. In cases where the FV said topical therapy, the DF reported amputation/resection/veterinarian (n = 2), systemic antibiotic (n = 4), trim (n = 12), block/lift (n = 13), or no lesion (n = 14). The lack of consistency in the responses provided by the DF may be indicative of his inability to determine appropriate treatment plans for these particular lesions.

Although the level of agreement was inconclusive for some categories for both diagnosis (i.e., fissures of the claw, abnormalities of the claw wall and lesions of the proximal limb) and treatment (i.e., systemic antibiotic and amputation/resection/veterinarian), in most cases, these rare categories are likely to be less important than those that are more prevalent within a herd. While the correct diagnosis and treatment of these less common lesions is still important, particularly in terms of dairy cow welfare, in the context of the entire herd, the more prevalent lesions are of greater importance as they have the potential to contribute more to production and economic losses.

For the ordinal variables LCS and maximum lesion severity, although $p_o$ was high, w*k* was low. While it was not appropriate to calculate prevalence indices for these variables, the matrices demonstrate that some scores were more prevalent than others (i.e., a high proportion of all ratings were in one or two of the cells of the contingency tables) resulting in the low w*k*. Therefore, it is unclear how to interpret these values.

The imbalance in the matrices for these ordinal variables may be due to the subjectivity involved in using the scoring systems associated with each variable. The outcomes of such scoring systems are highly dependent on individual interpretation which is influenced by their level of training and experience. Therefore, interpretation of the categories of each scoring system is likely to vary between raters, and may result in one rater systematically giving a higher or lower rating than the other. This appears to be the case between the FV-DF pair for both variables. For LCS, the DF consistently scored more cows as LCS 1 or 2 (normal or slight abnormality, n = 21% and 29%, respectively), compared to the FV (n = 7% and 9%, respectively). Similarly, for lesion severity, the DF consistently allocated scores 1 and 2 more frequently than the FV (DF: n = 41% and 57%, respectively; FV: n = 28% and 39%, respectively). The differences in scoring highlight the potential differences in training and experience of the raters. However, it is unknown how experienced either rater was in the particular scoring systems used in this study. It is assumed that the FV would have more knowledge and experience and therefore would be more discerning at detecting subtle indications of lameness and determining the severity of lesions than the DF.

This trend of the DF assigning lower scores for both lameness and lesion severity than the FV identifies potential implications for lameness diagnosis and treatment. Where the DF is rating the LCS of a cow as 1 or 2, where in reality it may actually be 3 or greater, there is less incentive for the dairy farmer to inspect these cows. As a consequence, the lame cow may go untreated until it is presenting more obvious and advanced signs. By this time, the welfare of the cow may be greatly compromised. Similarly, if the DF perceives a serious lesion to only be of mild severity, they may not see the urgency in treating nor be as concerned for the welfare of the cow. Ultimately this may mean that the DF perceives lameness to be less of a problem than it really is.

During this study, the DF identified 22% fewer lesions than the FV (DF: n = 114, FV n= 142); therefore, the DF observed and rated fewer lesions. In seven lameness events, the DF recorded that no lesions were present. Overall, the observation of fewer lesions may have reduced the probability for disagreement between the raters, thereby resulting in inflated inter-rater agreement results. The DF may have failed to identify these lesions because they were more subtle. Alternatively, the DF may have failed to recognise some lesions if they occurred concurrently with other lesions. This is supported in the data where the FV identified three or four lesions in one lameness event 13 times resulting in 48 lesions, the DF only identified three or four lesions in one lameness event three times, resulting in a total of 12 lesions. The identification of fewer lesions than are actually present, particularly failing to identify any lesion, has implications in practice as it means that lesions are going unobserved and therefore untreated, implicating dairy cow welfare.

### *Farm veterinarian and remote veterinarian*

For body region and tissue, the FV-RV pair demonstrated moderate to almost perfect agreement. This suggests that in most cases the raters were able to agree on the location of the lesions. For diagnosis and treatment, the pair demonstrated moderate and moderate to almost perfect agreement, respectively.

For diagnosis it was only possible to quantify the level of agreement for lesions of the sole and interdigital lesions. While this has prevented a full assessment of the level of agreement between the raters, lesions of the sole and interdigital lesions were the two major lesion types in this herd. The moderate agreement achieved may be considered suboptimal (although the maximum obtainable kappa indicated the potential for strong agreement between the raters); however, putting agreement of this nature into perspective is challenging because the degree of diagnostic agreement between two veterinarians examining lesions on an animal in person has not been established. This leads to the question of whether perfect (or almost perfect) agreement is even achievable as there will invariably be differences in diagnostic outcomes between two veterinarians. To the author's knowledge, no other studies investigating the remote diagnosis between veterinarians exist, however, tele-dermatology studies involving human patients suggest that agreement levels of $k \geq 0.63$ are acceptable levels to determine the tool effective in diagnosing skin lesions (Whited et al. 1991; Heffner et al. 2009; Shin et al. 2014).

A further consideration is that to some extent, a proportion of the disagreement may be attributed to the technology itself. For example, many images did not capture the entire foot as the location of some lesions precluded this from being possible. This means that some part of the foot would not be visible in the image and therefore was not available for the RV to take into consideration in their assessment. This introduces an increased risk of probability of misdiagnosis.

Although the agreement for diagnosis was moderate, the FV-RV pair have achieved higher agreement for treatment. The veterinarians achieved strong and almost perfect agreement for Block/trim and pain relief, respectively. While the agreement levels for systemic antibiotic, topical therapy, trim and amputation/resection/veterinarian were moderate, all except systemic antibiotic achieved the upper limits of the moderate threshold (i.e., agreement between raters approached strong levels of agreement). Further, topical therapy and amputation/resection/veterinarian had the potential for strong and almost perfect agreement respectively. Providing the correct treatment is arguably the most important element of the proposed tele-foot-health system. Therefore, the levels of agreement achieved between the pair provide evidence to suggest that the tele-foot-health system may be a successful tool for providing dairy farmers assistance in treating foot lesions in their dairy cows.

For maximum lesion severity, although $p_o$ was high, w*k* was weak. Similar to the FV-DF pair, the matrices demonstrate that some scores were more prevalent than others, resulting in the low w*k*. Therefore, it is unclear how to interpret these values.

### 4.4.2. Study limitations

There were several limitations identified in this study. First, there were a number of shortcomings recognised with the lameness data collection form used by the raters. These have been outlined in the methods. Further, the form did not allow for the raters to provide comments, however, the RV indicated making several notes on his forms to support his selections. We did not have access to the forms, therefore, we did not have access to these notes. A potential solution to the issues described in the methods would be to have raters mark on a diagram where the lesion they have identified is located. This may also aid in matching lesions between raters so that in future, analysis can be done at the lesion level, rather than the lameness event level.

Second, this study assessed only a single pair of FV and DF and FV and RV. Therefore, the results of this study are limited to the observations made by these raters based on their knowledge, experience and interpretation. Therefore, caution should be used in extrapolating the agreement results beyond this study. The study could be improved and provide more informative results by using multiple dairy farmers, farm veterinarians and remote veterinarians. However, this was a proof of concept study to establish the capability of the proposed tele-foot-health system before potentially undertaking a full-scale study.

Third, there were a number of categories with inconclusive results due to high prevalence indices. This highlights a major limitation of the *k* statistic, demonstrating that *k* is only a reliable measure of inter-rater agreement when specific conditions are met (i.e., in a heterogenous population). To ameliorate this, according to Hoehler (2000), a study population with trait prevalence’s near 50% is required for this type of study. However, obtaining trait prevalence’s near 50% for all of the categories included in this particular study is unlikely to be practical because some categories of the different variables are naturally less prevalent than others.

Fourth, this study was conducted using a single dairy herd. While the assessment of agreement between raters was based predominantly on the more prevalent categories of each variable, these may not be the most prevalent categories within other herds. To the authors knowledge, only three peer reviewed studies documenting the types of lesions occurring in Australian herds exist. The first, based on 214 dairy cows from 83 herds located in Queensland reported that interdigital lesions, digital lesions, lesions of the sole and fissures of the claw were the most prevalent lesion types (McLennan 1988). The second study, based on 783 dairy cows located in East Gippsland reported that abnormalities of the claw, lesions of the sole and interdigital lesions were the most prevalent lesion types (Jubb & Malmo 1991). The final study, based on 73 herds in south-western Victoria reported overworn sole, bruised sole and stone between claws were the most prevalent lesion types (Harris et al. 1988). While interdigital lesions and lesions of the sole were identified as the most prevalent lesion types in this study, it was not possible to assess the other lesions. Therefore, further research is required to determine the usefulness of the tele-foot-health system to other Australian dairy herds.

Fifth, the lameness events in this study were only ever determined by the DF. The results show that locomotion scores of 3 and 4 were the most frequent scores observed by both the FV and DF. Therefore, it is possible that the lameness events identified by the DF may represent cows with more obvious lameness lesions and therefore may not represent the true spectrum of lameness that occurred in the study population during the study period. Because it is generally easier to diagnose more advanced lesions, this may have compromised the agreement analysis, achieving higher agreement than had a wider spectrum of lesions been included in the study. Further, given that the literature indicates that dairy farmers underestimate the number of lame cows in their herds (Wells et al. 1993; Espejo et al. 2006; Šárová et al. 2011), it is possible that more lameness events would have been identified if the FV had examined the herd daily during the study period. These potential lesions that were unidentified may have represented the less obvious lesions.

Finally, the levels of agreement obtained between the FV and RV may be specific to the imaging quality of the mobile phone device used in this study. In real world applications (i.e., on any given dairy farm) where dairy farmers use their own mobile phone device, image capture quality may vary due to the variability of picture capture quality of the particular mobile phone device used. In addition, picture quality may vary due to user ability to take an image that is not only clear but also captures the lesion from appropriate angles to facilitate diagnosis. In this study, the images that were sent to the RV were captured by the FV (retrospectively, the RV stated that the majority of the images received were of high quality). However, the aim of the proposed tele-foot-health system is to have dairy farmers take photographs from their mobile devices and send these images to a veterinarian for a proposed diagnosis and treatment plan, thereby eliminating the need for a veterinarian to visit the farm. Therefore, this study was performed using optimized conditions (using a single mobile phone, with one user (considered to have expert knowledge) taking the images, using specific camera settings and protocols) which do not accurately correspond to the true application of the proposed tele-foot-health system. Given that compared to the DF, the FV would have greater knowledge of lameness lesions and better insight into what the RV would need to see in the image to make a diagnosis, it is possible that the quality of the images (in terms of capturing the correct angle/s to effectively show the lesion) may be higher than had the DF taken the images, facilitating RV diagnosis. Therefore, the levels of agreement obtained may not truly reflect the efficacy of the tele-foot-health system. However, the impact that image quality has on the ability of an individual to make a correct diagnosis is unclear in the literature with studies presenting conflicting results. In the field of tele-dermatology, several studies have indicated that image quality does not affect the tele-dermatologist's ability to make a correct diagnosis (Kvedar et al. 1997; Krupinski et al. 1999; Weingast et al. 2013). Conversely, other studies indicate that poor image quality is an issue, reporting an inverse correlation between image quality and correct diagnosis (High et al. 2000b; Du Moulin et al. 2003; Landow et al. 2014) .

## 4.5. Conclusions

Overall, the FV-DF pair demonstrated poor to almost perfect agreement while the FV-RV pair demonstrated moderate to almost perfect agreement. For the FV-DF, the weak levels of agreement related to diagnosis and treatment suggesting that the DF may need more assistance in diagnosing and treating foot lesions causing lameness in their dairy herds. The moderate to almost perfect agreement achieved between the FV-RV indicates the potential for success of the proposed tele-foot-health system. However, further trials are necessary to further investigate and validate its use.

# 5. Chapter 5: Understanding dairy farmer intentions to make improvements to their management practices of foot lesions causing lameness in dairy cows

## 5.1. Introduction

Foot lesions causing lameness in dairy cows are linked to reductions in milk yield (Green et al. 2002; Reader et al. 2011) poor reproductive performance (Collick et al. 1989), and premature culling (Booth et al. 2004), culminating in significant economic burden to individual dairy farmers and the dairy industry. In addition, foot lesions are often associated with pain, and therefore compromise dairy cow welfare (Whay et al. 2003).

Dairy farmers play a primary role in the management of foot lesions affecting their dairy herds. The choices that they make in managing foot lesions contribute to the level of economic burden and dairy cow welfare outcomes. Despite what is known about the causes and consequences of foot lesions, they remain a large problem in many Australian dairy herds. This suggests that the current management practices used by dairy farmers may be inadequate. Therefore, there is potential for dairy farmers to consider making changes to improve their current management practices of foot lesions.

The current literature has focused on the development of methods to aid dairy farmers in the detection of lameness and foot lesions. These methods are developed based on two assumptions: i) that dairy farmers are equipped with the appropriate knowledge to determine the need for such methods (i.e., dairy farmers understand the magnitude of the implications associated with foot lesions), and therefore, ii) dairy farmers intend to make improvements to their current management practices. Based on these assumptions, it is expected that dairy farmers will make the decision to adopt new methods to reduce the burden of foot lesions. However, Ajzen et al. (2011) demonstrates that even though an individual may be equipped with the correct knowledge, this does not necessarily lead to the desired behaviour. Therefore, Ajzen et al. (2011) suggests rather than ensuring that the population in question have the correct information, we need to establish how the information they do hold (whether correct or not) affects their intentions and behaviours. Following this, it is possible to: i) challenge beliefs that prevent the adoption of the desired behaviour, ii) strengthen existing beliefs that support the adoption of the desired behaviour, or iii) facilitate the formation of new beliefs that promote the desired behaviour (de Leeuw et al. 2015). Therefore, understanding dairy farmer beliefs is at the core of not only understanding their intentions but also facilitating positive behavioural change to increase their intentions to improve their current management practices of foot lesions causing lameness.

This study is based on a social–psychology framework, the Theory of Planned Behaviour (TPB) (Ajzen 1991a). The theory proposes three psychological constructs, attitude, subjective norm and perceived behavioural control, which in combination, are hypothesised to determine an individual's intention to perform a behaviour. Intention, in turn, is proposed to be the immediate antecedent of behaviour. Attitude, subjective norm, and perceived behavioural control are said to be determined by an individual's behavioural, normative and control beliefs, respectively. Investigating these beliefs allows the identification of cognitive drivers or barriers that may influence an individual's decision to participate (or not) in a particular behaviour. Once identified, they can be used to develop interventions and strategies that target the beliefs with the strongest influence on decision making.

The behaviour of interest in this study is dairy farmer intentions to make improvements to their management practices of foot lesions causing lameness in their dairy cows in the next 12 months. A Dutch study has used the TPB to examine the role of underling beliefs in determining dairy farmers' intentions to improve dairy cow foot health (Bruijnis et al. 2013). Dairy farmers in Australia face different challenges to dairy farmers in the northern hemisphere as cows are predominantly based at pasture rather than housed for all or most of the year, typical of the northern hemisphere. This results in different practices, different lesions and different prevalences. Therefore, it is proposed that the underlying beliefs and therefore intentions are likely to differ.

In relation to making improvements to their management practices of foot lesions causing lameness in their dairy cows over the next 12 months (the behaviour), the objectives of this chapter are to:

- Identify the advantages and limitations that dairy farmers associate with the behaviour (behavioural beliefs).
- Identify the individuals or groups that dairy farmers think would approve and disapprove of them performing the behaviour (normative beliefs).
- Identify factors or circumstances that dairy farmers believe would facilitate and constrain them from performing the behaviour (control beliefs).
- Determine dairy farmer intentions to perform the behaviour (behavioural intention).

- Determine the individual behavioural, normative and control beliefs that act as cognitive drivers and barriers towards dairy farmer performing the behaviour.
- Quantify the extent that attitude, subjective norm and perceived behavioural control contribute to dairy farmer intentions to perform the behaviour.

## 5.2. Methodology

### 5.2.1. Ethics approval

Prior to commencing this study, ethical approval was sought from the University of Queensland Human Ethics Unit. The Approval Number is 2016001140. A copy of the ethics approval letter is located in Appendix 17.

### 5.2.2. Theoretical framework and hypotheses

The theoretical framework for this study is based on the Theory of Planned Behaviour (TPB). The theory has been described in detail in Chapter 2, Section 2.5 of this thesis. As discussed, the constructs attitude, subjective norm and perceived behavioural control may be measured using direct, indirect or both direct and indirect measures in a questionnaire. This study utilised both measures, therefore creating seven constructs in total (intention, direct and indirect attitude, direct and indirect subjective norm, and direct and indirect perceived behavioural control). As discussed in Chapter 2, Section 2.5, the literature (Budd et al. 1984; Ajzen 1991a; Gagne & Godin 2000) suggests that behavioural belief strength (bs), normative belief strength (ns) and control belief power (cp) may be all that is required to formulate the indirect measures of the constructs. Therefore, outcome evaluation (oe), motivation to comply (mc) and control belief strength (cs) were omitted form the framework used in this study (Figure 5-1).

As depicted in Figure 5-1, there is not a direct relationship between the individual behavioural, normative, and control beliefs with intention (these relationships are represented by the black dotted lines in Figure 5-1). However, it is assumed that the more positive the behavioural, normative and control beliefs, the more positive the attitude, subjective norm and perceived behavioural control and therefore intention to perform the behaviour (Ajzen 1991a). Therefore, the following hypotheses were proposed:

- Hypothesis 1. Each individual behavioural belief is significantly correlated with dairy farmer intentions to make improvements to their current management practices of foot lesions.

- Hypothesis 2. Each individual normative belief is significantly correlated with dairy farmer intentions to make improvements to their current management practices of foot lesions.
- Hypothesis 3. Each individual control belief is significantly correlated with dairy farmer intentions to make improvements to their current management practices of foot lesions.

Behavioural, normative and control beliefs that demonstrate a significant and positive correlation with intention are referred to as cognitive drivers (i.e., individuals who hold the particular behavioural, normative or control belief are more likely to express an intention to participate in the behaviour of interest compared to those who do not hold that particular behavioural, normative or control belief). Conversely, behavioural, normative and control beliefs with a significant and negative correlation indicate a cognitive barrier (i.e., individuals who hold the particular behavioural, normative or control belief are less likely to demonstrate an intention to participate in the behaviour of interest than those who do not hold that particular behavioural, normative or control belief). The behavioural, normative and control beliefs acting as cognitive drivers can be strengthened in the target population to facilitate adoption of the target behaviour.

The sums of the statements used to measure behavioural belief strength, normative belief strength and control belief power (i.e. $\sum bs_i$, $\sum ns_j$ and $\sum cp_k$), resulted in the indirect measures of attitude, subjective norm, and perceived behavioural control, respectively. These indirect measures could only substitute as measures of the three constructs where they correlate highly with the corresponding direct measures (Ajzen & Driver 1991). Therefore, the following hypotheses are proposed:

- Hypothesis 4. The indirect measure of attitude is significantly and highly correlated with the direct measure of attitude.
- Hypothesis 5. The indirect measure of subjective norm is significantly and highly correlated with the direct measure of subjective norm.
- Hypothesis 6. The indirect measure of perceived behavioural control is significantly and highly correlated with the direct measure of perceived behavioural control.

Both the direct and indirect measures of attitude, subjective norm and perceived behavioural control were postulated to have a relationship with intention. In general, the intention to perform a behaviour is stronger when attitude and subjective norm are more favourable, and when perceived behavioural control is greater. Therefore, the following hypotheses were derived:

- Hypothesis 7a: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the direct measure of their attitude
- Hypothesis 7b: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the indirect measure of their attitude
- Hypothesis 8a: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the direct measures of their subjective norm
- Hypothesis 8b: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the indirect measures of their subjective norm
- Hypothesis 9a: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the direct measures of their perceived behavioural control.
- Hypothesis 9b: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the indirect measures of their perceived behavioural control.

Empirical research indicates that intentions provide an accurate measure of actual behaviour (Ajzen 2005). Therefore, the link between intention and actual behaviour was not tested in this study.

### 5.2.3. Stages of a Theory of Planned Behaviour study

Conducting a TPB study consists of five major stages, each consisting of a number of steps (Figure 5-2). Stage 1 and Stage 2 are for the development of the indirect, direct and intention statements, respectively. Stage 3 combines demographic data along with the indirect, direct and intention statements to form the questionnaire. Stage 4 involves conducting a pilot of the questionnaire and making amendments as necessary. Finally, Stage 5, concerns questionnaire distribution and data analysis. The specific procedures used for each stage for this study are described below.

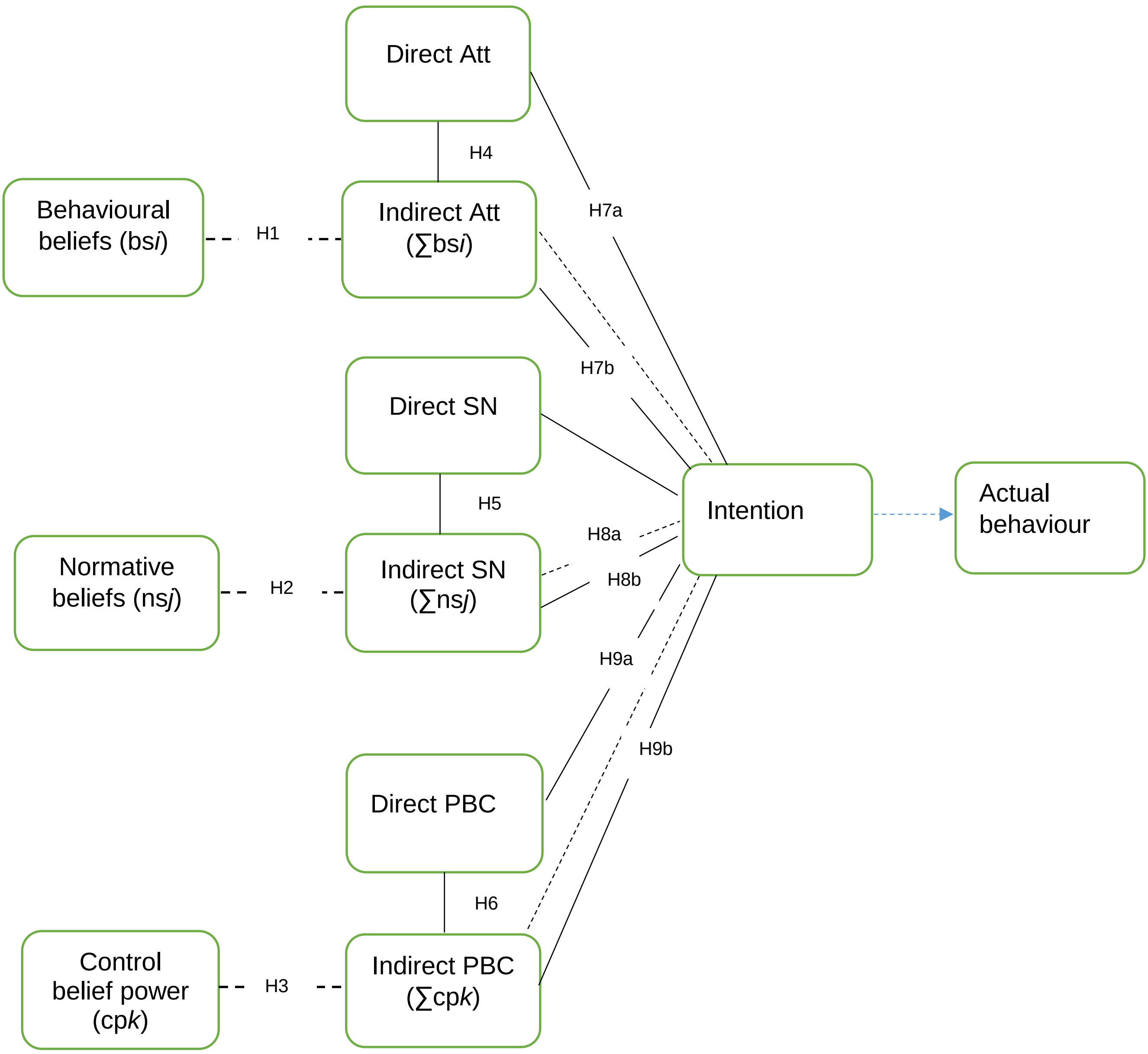


Figure 5-1: The theoretical framework used in this study, based on the Theory of Planned Behaviour, adapted from Ajzen (1985).Att: attitude, SN: subjective norm, PBC: perceived behavioural control, $bs_i$: the $_i$th outcome of behavioural belief strength, $ns_j$: the $_j$th referent of normative strength, $cp_k$: the $_k$th factor of control belief power. H1 – H9 represent the proposed hypotheses.

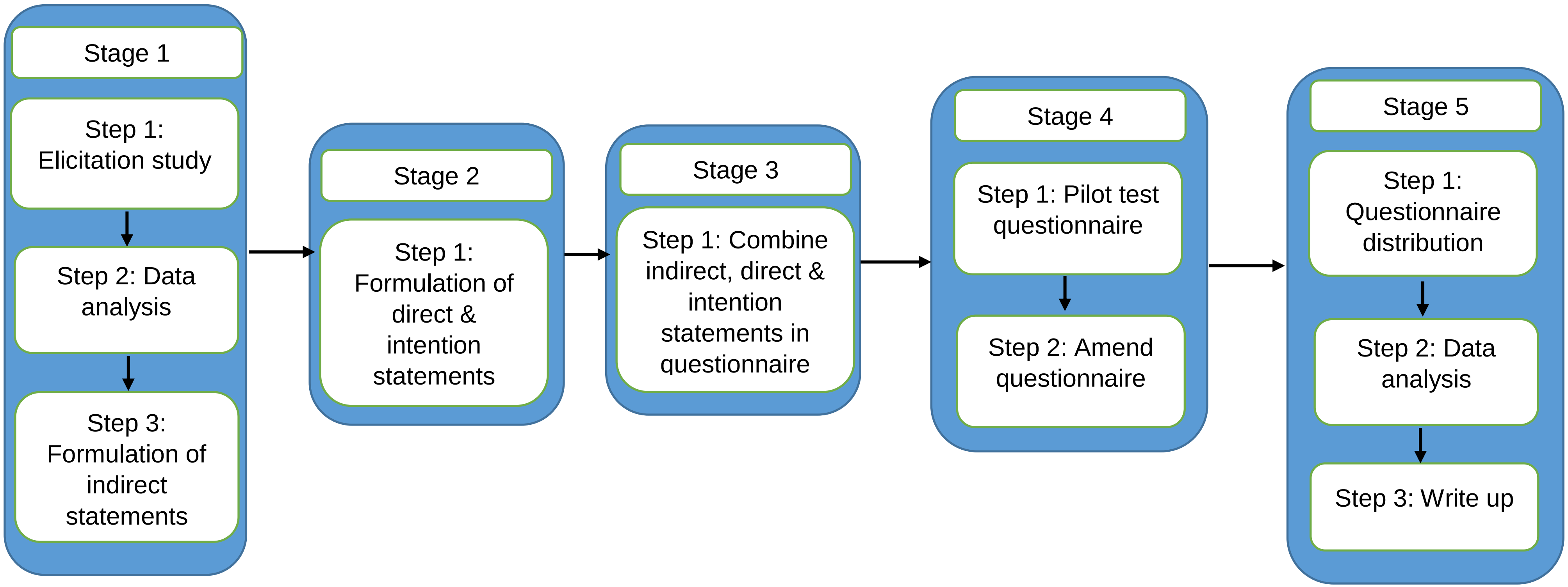


Figure 5-2: The five major stages involved in conducting a Theory of Planned Behaviour study.

### *Stage 1*

#### Step 1: Elicitation study

Thirty-three dairy farm managers (herein referred to as dairy farmers) were approached to respond to a short, open ended questionnaire. The dairy farmers approached were a convenience sample, recruited by one researcher who had knowledge of dairy farmers located between Kenilworth in Queensland, to Lismore in North-eastern New South Wales. The dairy farmers were initially contacted by telephone, during which the researcher provided details about the questionnaire. The dairy farmers were asked if they would like to participate in the questionnaire. If they agreed they were provided with a number of options to participate. These were: i) via telephone, either at the time of the initial call or at a later time that suited the dairy farmer, ii) during a face-to-face interview at a time that suited the dairy farmer, iii) via a posted hard-copy, that the dairy farmer could return by post once completed, or iv) via email as an attached Word document that the dairy farmer could return as a posted hard copy or as an email attachment. For those who participated via telephone or face-to-face, the researcher asked the dairy farmer the questions and then wrote down the responses provided. The dairy farmer was then asked to check that their responses had been accurately transcribed.

The questionnaire (Appendix 18) was comprised of six questions to elicit dairy farmers' behavioural, normative and control beliefs. The questions related to the advantages and disadvantages of making improvements to their current management practices of foot lesions (behavioural beliefs), individuals or groups who would approve or disapprove of them making improvements to their current management practices of foot lesions and factors or circumstances that would enable or constrain their ability to make improvements to their current management practices of foot lesions (control beliefs).

#### Step 2: Data analysis

Twenty-three dairy farmers responded to the elicitation questionnaire. Five of the respondents agreed to be interviewed by telephone either at the time of the initial call (n = 2) or at a later time that suited them (n = 3), 10 agreed to a face-to-face interview at a time that suited them, five returned the questionnaire by post (however, one did not answer the questions framed in the questionnaire and was excluded), and three returned the questionnaire as an email attachment (Word® document). Therefore, there were 22 usable questionnaires.

The responses from the six elicitation questions were extracted and entered into a Microsoft Excel® spreadsheet. Similar responses were grouped together, forming the beliefs. These were then tallied to identify the most frequently mentioned behavioural, normative and control beliefs (Appendix 19). To determine the modal salient beliefs, and for the sake of questionnaire brevity, it was decided to initially include the five most frequently mentioned beliefs for each of behavioural, normative and control beliefs (Table 5-1).

Table 5-1: The five most frequently mentioned beliefs for each of behavioural, normative and control beliefs included in the first draft of the full questionnaire.

| Behavioural beliefs |
| --- |
| Improved milk production |
| Improved welfare |
| Reduced costs (veterinarian visits, treatment/drugs) |
| Cost involved for effort put in |
| Lack of time to invest in change |
| Normative beliefs |
| Animal welfare groups |
| Consumers |
| Staff |
| Visitors/tourists |
| Other farmers |
| Control beliefs |
| Better equipment and facilities |
| Cost outweighs benefit |
| Lack of skills/knowledge/training |
| Better knowledge of lameness detection/mobility scoring |
| Lack of time available to implement practices |

### Step 3: Formulating indirect statements

The modal salient behavioural, normative and control beliefs identified were used to construct statements for the indirect measures of the constructs, attitude, subjective norm and perceived behavioural control, respectively (Appendix 20). The wording of the statements was based on the recommendations of Ajzen (n.d.) and Francis et al. (2004). All responses to the statements were elicited via a 1–7-point scale with 1 being the most negative response and 7 being the most positive response (e.g.: very unlikely–very likely, strongly disagree–strongly agree).

### *Stage 2*

#### Step 1: Formulating statements for direct constructs and intention

The statements developed for the direct constructs, attitude, subjective norm, perceived behavioural control and for intention are presented in Appendix 21. Similar to the indirect statements, all responses were elicited via a 1–7-point scale. The specific requirements for each construct are detailed below.

##### Direct attitude

A single stem sentence which defines the behaviour under investigation was used followed by four bipolar adjectives, as recommended by Ajzen (n.d.). Both instrumental (whether the behaviour achieves something (e.g., *useful – worthless*) and experiential adjectives (how it feels to perform the behavior (e.g., *pleasant - unpleasant*) were used (Francis et al. 2004; Ajzen n.d.).

##### Direct subjective norm

The statements for subjective norm referred to the opinions of important others in general, rather than specific individuals or groups as this is achieved using indirect statements (Francis et al. 2004; Ajzen n.d.).

##### Direct perceived behavioural control

For direct perceived behavioural control, the statements used reflect an individual's confidence that they are capable of performing the behaviour in question. This was achieved by assessing the individual's self-efficacy and their perceived controllability of the behaviour (Francis et al. 2004).

##### Intention

Three statements were formulated to optimally capture intention (Francis et al. 2004). These were framed as: "I expect to perform behaviour X", "I want to perform behaviour X", and "I intend to perform behaviour X" (Francis et al. 2004).

### *Stage 3*

#### Step 1: Questionnaire design

The questionnaire was made up of two sections. The first section consisted of questions to gather demographic data about the study population. In addition, questions regarding the current management and occurrence of lameness on each farm were asked. The second section combined the statements for the indirect and direct constructs and those for intention. The order of these statements appearing in the questionnaire were mixed, as recommended by Ajzen (n.d.), so that statements used to assess attitude were interspersed with statements used to assess subjective norms, perceived behavioural control and intention. Although Ajzen (n.d.) recommends that the ends of the scales for each statement are a mix of positive and negative to minimise the risk of 'response set' (the tendency of individuals to respond to statements in the same way) (Francis et al. 2004), all endpoints were kept consistent in this study to avoid confusion.

The first draft of the questionnaire is presented in Appendix 22.

### *Stage 4*

#### Step 1: Pilot test questionnaire

Fifteen dairy farmers from a database held by Scibus and five dairy farmers who participated in the elicitation questionnaire were contacted to participate in a pilot of the first draft of the questionnaire. The aim of the pilot was to gain feedback from dairy farmers to determine: i) if the questionnaire addressed the project aims, ii) if the questions were easy to understand and answer (for simplicity, both the questions and statements from Sections 1 and 2 were referred to as questions in communication with the dairy farmers), and iii) if the questions were appropriate to ask dairy farmers.

The dairy farmers were asked to complete the questionnaire and then respond to a number of questions to help the research team determine these aims. The dairy farmers were provided with an information sheet detailing the instructions (Appendix 23), the questionnaire and a word document to provide their feedback and comments (Appendix 24). The farmers were also given the option to put their comments directly into the questionnaire document or to write them in an email addressed to a member of the research team or to contact a member of the research team via telephone.

Five dairy farmers responded to the pilot questionnaire (male = 4, female = 1) which is the minimum number of respondents as suggested by Ajzen (n.d.) (Appendix 25). Four out of the five dairy farmers found that the questions were easy to answer. The questionnaire was found to be a little or somewhat repetitive with one dairy farmer who indicated that questions relating to subjective norms were repetitive. Two of the five dairy farmers suggested that the questionnaire was too long. All dairy farmers indicated that the questions were easy to understand. Two dairy farmers suggested that not all dairy farmers have lameness issues on their farm and therefore may not be inclined to respond to the questionnaire. Three dairy farmers indicated that there were too many welfare questions which may be inappropriate. Three dairy farmers reported the time taken to complete the questionnaire; the times ranged from 15 to 55 minutes.

Internal consistency of the direct constructs was tested using Cronbach's alpha coefficient (α) (Ajzen & Driver 1991). This describes the extent to which the statements used for a given construct measure the same concept (i.e. that the scores obtained for each statement correlate highly with each other and are therefore considered reliable). Values ≥60 indicated that the statements measured the same concept (Francis et al. 2004). Cronbach's alpha for direct attitude, direct subjective norm and direct perceived behavioural control were 0.97, 0.69, and 0.71, respectively. Internal consistency was not a requirement of the indirect constructs (Ajzen & Driver 1991). This is because individuals can have salient beliefs that are not consistent with the overall direction of their intention, therefore it is possible for the elicited beliefs to be inconsistent with each other (Ajzen & Driver 1991).

### Step 2: Amendments to questionnaire

In light of the comments provided from the pilot, a decision was made to reduce the length of the questionnaire. This was achieved in three ways. First, for indirect attitude, indirect subjective norm and indirect perceived behavioural control, instead of five beliefs, only the three most frequently stated beliefs for each construct were included in the final questionnaire.

Second, for direct attitude, originally four statements were used, each using the same single stem sentence, followed by a different bipolar adjective. Normally, the stem sentence would be singular and the four bipolar adjectives would follow. However, these were separated in the first draft of the questionnaire so that the statement did not appear too large or complicated. This separation is likely to have contributed to the perceived repetitiveness as the single stem sentence was repeated four times throughout the questionnaire. Therefore, in the final questionnaire the single stem sentence was only included in the questionnaire once, followed by the bipolar adjectives. Additionally, two of the four bipolar adjectives were removed because the research team felt that they might have been perceived as unusual or unclear to the respondents. A new bipolar adjective was added so that the construct was assessed with three bipolar adjectives (Table 5-2).

Finally, only two statements were retained for direct perceived behavioural control. This was because one of the statements was framed in the same way as the single stem sentence for direct attitude and therefore, could not be considered to have measured direct perceived behavioural control. The bipolar adjectives of this statement were used for direct attitude in place of those removed. Further, direct perceived behavioural control should be assessed by both an individual's self-efficacy and their beliefs about the controllability of the behaviour. Because questionnaire size was of primary concern, a decision was made to include one statement for each of these components, rather than two statements, which would have resulted in four statements for the construct.

At this point it was decided to have an individual with expertise in TPB studies view the questionnaire to offer final advice. She suggested the following amendments: i) rephrase the statements used for intention as the structure used in the pilot, taken from (Francis et al. 2004) was outdated. Therefore, the intention statements were amended to be framed as: "I will try to perform behaviour X", "I plan to perform behaviour X", and "I intend to perform behaviour X" as framed by (Ajzen n.d.), and, ii) for the direct subjective norm statements it was recommended to include a descriptive norm (what important others actually do) as the current statements were all injunctive (what important others think an individual should do). The descriptive norm was initially excluded because the research team believed that it would narrow the pool of 'important others' to other dairy farmers, thus becoming more an indirect measure. However, its inclusion was considered pertinent. Therefore, the statement 'Individuals who influence my behaviour would think that I should make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months', was replaced by 'Individuals who are important to me would make improvements to their current management practices of foot lesions in their dairy herd in the next 12 months' in the final questionnaire.

Cronbach's alpha coefficient was calculated for the three constructs using the retained statements. Internal consistency was 0.96, 0.65 and 0.60 for direct attitude, direct subjective norm and direct perceived behavioural control respectively. The final questionnaire used for this study is presented in Appendix 26.

Table 5-2: Bipolar adjectives retained in the final questionnaire for the construct direct attitude.

| Item | Included/excluded |
|---|---|
| Good – Bad | Included |
| Valuable – Worthless | Excluded |
| Useful – Useless | Included |
| Easy - Difficult | Included |
| Important – Unimportant | Excluded |

### *Stage 5*

#### Step 1: Questionnaire distribution

##### Population

Participants were recruited from a number of dairy industry databases, these were: Dairy South Australia (DairySA), Dairy New South Wales (DairyNSW), North Coast Fresh Food & Cold Storage Co-operative Company (NORCO), AusDairyL, Dairy Farmers Milk Co-operative, Scibus, and South-Coast and Highlands Dairy Co-operative. Full details of each of these databases are detailed in Table 5-3. In addition, dairy farmers who participated in the elicitation questionnaire were also invited to complete the final questionnaire (n = 33).

Table 5-3: Details of each dairy industry organisation distributing the questionnaire including location and approximate number of dairy farmers in each database.

| Dairy organisation | Description of organisation | Location of dairy farmers in database | Approximate number of dairy farm managers in database |
|---|---|---|---|
| DairySA | The South Australian subset of Dairy Australia. | South Australia. | 200 |
| DairyNSW | The New South Wales subset of Dairy Australia. | New South Wales. | 477 |
| NORCO | A dairy co-operative owned by member suppliers who operate Australian dairy farms. | South East Queensland (Kenilworth and Kingaroy to the NSW border) and North-East NSW (Gloucester to the QLD border). | 210 |
| AusDairyL | An online dairy farmer forum provided as a free service by Dairy Australia and operated by a Dairy Consultant. | Australia-wide. | 600 |
| Dairy Farmers Milk Co-operative | An independent, farmer-owned co-operative. | Atherton tablelands down the east-coast of Australia to South Australia | 225 |
| Scibus | A consultation service. | QLD, NSW and Tasmania | 25 |
| South-Coast and Highlands Dairy Co-operative | A subset of Dairy Australia. | NSW (Wollongong, Shellharbour, Kiama, Shoalhaven and Wingecarribee). | 46 |

### Distribution

The platform Google Forms was used to design and distribute the questionnaire online. The questionnaire sent to each group of dairy farmers contained the same questions but the questionnaire was individually coded to enable identification of the target group of dairy farmers. In doing this, it was possible to determine where the responses had come from.

Each organisation agreed to nominate an individual to act as gatekeeper for distribution of the questionnaire. The questionnaire was predominantly distributed online, either via newsletter, email or discussion forum. Only individuals who participated in the elicitation study were offered a hard copy version. Full details of how each gatekeeper distributed the questionnaire to the target population are detailed in Appendix 27. In each case, each organisation was provided with a link to the online questionnaire and the Participant Information Sheet (Appendix 28). The questionnaire was initially distributed during April and May 2017, depending on the timing that suited each organisation. The questionnaire was made available for six weeks for each study population. Each organisation was prompted to re-distribute the questionnaire every two weeks during this period as a reminder to prospective participants.

### Step 2: Data analysis

Data from the questionnaire were organised in Microsoft Excel® spreadsheets and analysed using Stata® version 14.2 These data were initially checked for missing data and responses that did not make sense. For Section 1 of the questionnaire, the mean, standard deviation, median, interquartile range, range and frequency of responses were calculated as appropriate. The mean was used as measure of central tendency where farm/farmer data were normally distributed, while the median was used for skewed data.

For Section 2, presentation of the data in the spreadsheet was as follows: each column represented a statement; the statements for each construct were placed side-by-side. Each row contained the responses of a single dairy farmer to the statements. For each direct construct and intention, following the set of statements used to measure the construct in question, there was a column for the mean value for the set of statements for that construct for each dairy farmer (i.e., for each direct construct, there were 56 mean values). The mean value of direct attitude, direct subjective norm and direct perceived behavioural control for each dairy farmer could then be correlated with the mean value for intention. Because there was no interest in individual dairy farmers, overall mean values were calculated for the three direct constructs and for intention and used as a summary measure.

For the indirect constructs, the indirect attitude item ‘Making improvements to my current management practices of foot lesions in my dairy herd will not be worth the potential cost involved’ was negatively phrased. Therefore, prior to analysis the responses were recoded so that the higher numbers would reflect a positive attitude toward the target behaviour (e.g., a score of 6 becomes a score of 2, a score of 4 remains a 4). For each indirect construct, the scores provided by each dairy farmer for each statement were summed to provide an overall score for each dairy farmer (i.e., in place of the column for the mean value used for the direct constructs). Similar to the direct constructs, the overall score of indirect attitude, indirect subjective norm and indirect perceived behavioural control for each dairy farmer could then be correlated with the mean value for intention. As there was no interest in individual dairy farmers, the mean of each construct was used as a summary (Francis et al. 2004). The range of possible values for the summary measure was 3 to 21 (using the 7-point Likert scale and three statements for each indirect construct).

The summary measures for each construct were interpreted as described in Tale 5-4. For all direct, indirect and intention statements, the median, interquartile range and frequency of responses were calculated.

Table 5-4: Interpretation of the summary measures used for direct (range of values 1 – 7) and indirect (range of values 3 – 21) constructs. Where 1 & **3 - 5** = very weak, 2 & **6 - 8** = weak, 3 & **9 - 11** = low, 4 & **12** = neutral, 5 & **13 - 15** = moderate, 6 & **16 - 18** = strong, 7 & **9 - 21** = very strong. Values for indirect constructs are in bold.

| | Construct | | | |
|---|---|---|---|---|
| Summary measure for direct/indirect construct | Direct/indirect attitude | Direct/indirect subjective norm | Direct/indirect perceived behavioural control | Intention |
| 1 – 3 & **3 - 5** | Overall, dairy farmers are not in favour of making improvements to their current management practices of foot lesions causing lameness in their dairy cows. The lower the number the more negative the attitude toward performing the target behaviour. | Overall dairy farmers do not experience social pressure to make improvements to their management practices of foot lesions causing lameness. The lower the score the lower the social pressure to do the target behaviour. | Overall, dairy farmers do not feel in control of making improvements to their management practices of foot lesions causing lameness. The lower the score, the lower the perceived level of control over the target behaviour. | Overall dairy farmers do not have intentions to make improvements to their management practices of foot lesions causing lameness. |
| 4 & **12** | Overall dairy farmers are neither against nor in favour of making improvements to their management practices of foot lesions causing lameness. | Overall dairy farmers neither experience social pressure or a lack of social pressure to make improvements to their management practices of foot lesions causing lameness. | Overall dairy farmers neither feel out of control or in control of making improvements to their management practices of foot lesions causing lameness. | Overall dairy farmers neither have no intentions or intentions to make improvements to their management practices of foot lesions causing lameness. |
| 5 – 7 & **13 – 21** | Overall, dairy farmers are in favour of making improvements to their current management practices of foot lesions causing lameness in their dairy cows. The higher the number the more positive the attitude toward performing the target behaviour. | Overall, dairy farmers experience social pressure to make improvements to their management practices of foot lesions causing lameness. The higher the score the greater the social pressure to do the target behaviour. | Overall, the dairy farmer feels in control of making improvements to their management practices of foot lesions causing lameness. The higher the score, the greater the perceived level of control over the target behaviour. | Overall dairy farmers do have intentions to make improvements to their management practices of foot lesions causing lameness. |

As the responses to each statement were measured using an ordinal scale, these data are not likely to conform to the assumptions of normal distribution (Garforth et al. 2006). Therefore, non-parametric tests were used as these are considered more robust than parametric tests (Garforth et al. 2006). The Spearman rank correlation coefficient ($r_s$) was used to test the null hypothesis of each alternative hypothesis proposed in Section 5.2.2. The Spearman rank correlation coefficient measures the strength and direction of the monotonic relationship between two variables rather than the strength and direction of the linear relationship, which the corresponding parametric test, Pearson correlation coefficient, determines (Yitzhaki & Schechtman 2012). A monotonic relationship is one where although the variables tend to move in the same relative direction, they do not necessarily move at the same rate, resulting in a curved pattern in the data (Yitzhaki & Schechtman 2012).

For the hypotheses involving the direct and indirect constructs, there were specific criteria to meet before each hypothesis could be tested (Figure 5-3). These were as follows: It was only appropriate to use the overall mean value of direct attitude, subjective norm and perceived behavioural control where internal consistency of $\alpha \geq 60$ was achieved. If this was achieved, it was appropriate to assess the correlation between each direct construct with intention and each direct construct with their respective indirect counterpart. Where $\alpha < 60$, it was only appropriate to correlate the individual statements of both direct and indirect constructs with intention. This is because the indirect constructs could only substitute as measures of attitude, subjective norm and perceived behavioural control where they demonstrate a strong correlation with the corresponding direct measures (Ajzen & Driver 1991). Given that in the literature, correlations between direct and indirect constructs are often of only a moderate magnitude, for the purpose of this study, moderate correlations between direct and indirect constructs were considered acceptable. While no guidelines on interpreting correlation coefficients specific to TPB studies were found, the following general limits recommended by Swinscow (1997) were used for this study: 0 – 0.19 = very weak, 0.2 – 0.39 = weak, 0.40 – 0.59 = moderate, 0.60 – 0.79 = strong, 0.81 – 1 = very strong  While these limits are arbitrary, they were selected as the limits for moderate and strong are consistent with correlations reported in the literature determined to be moderate and strong (Ajzen 1991a).

The Mann–Whitney U test using the ‘porder’ function (Conroy 2012) was conducted to determine if there were differences between the following groups with respect to intention: i) gender (male versus female); ii) age of dairy farmer, young (≤ 53) versus old (≥ 54) (cut points for young versus old dairy farmers were determined using the mean dairy farmer age from data reported by Dairy Australia (2017); iii) milk production, high producers (≥ 1,550,000) versus low producers (≤ 1,490,000) (cut points for high versus low milk producers were determined using the mean milk production value reported by Dairy Australia (2016); or, iv) farm size, large herd size (≥ 273) versus small herd size (≤ 272) (cut points for large versus small farm size were determined using the mean herd size value reported by Dairy Australia (2016). For groups demonstrating significant differences, the median, interquartile range and frequency of responses were calculated for intention. The median and interquartile range were also calculated for indirect statements.

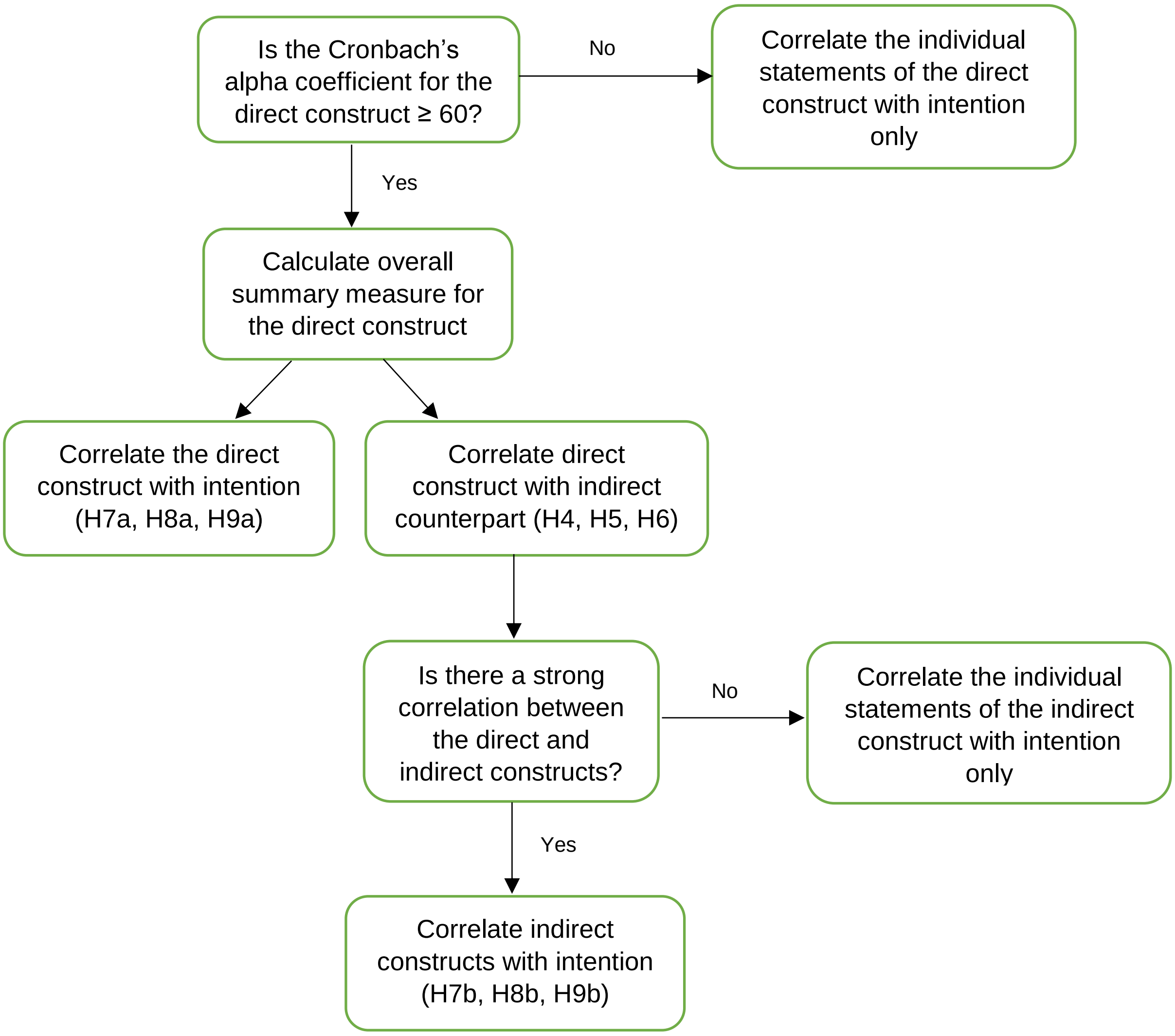


Figure 5-3: Flow diagram demonstrating the conditions under which it was appropriate to test the hypotheses involving the direct and indirect constructs. H1 – H9 represent the proposed hypotheses.

## 5.3. Results

### 5.3.1. Response rate and omissions

Fifty-eight dairy farmers completed the questionnaire. The questionnaires of dairy farmers who did not fill in all the questions based on the theoretical framework were not included in the analyses (n = 2). Therefore, there were 56 usable questionnaires.

The number of dairy farmers who completed the questionnaire and were included in the analysis from each organisation are displayed in Table 5-5. Most organisations had dairy farmers located from more than one Australian state, therefore it was not possible to determine the frequency of responses per state. Additionally, there is the potential for overlap between some of the populations as the dairy farmers may belong to more than one group. The extent of this potential overlap is unknown. However, it is unlikely that a respondent would have completed the questionnaire more than once. The overall response rate was very low (approximately 3%).

Table 5-5: The number of dairy farmers (n = 56) completing the questionnaire who were included in the analysis from each organisation.

| Dairy organisation | Frequency of responses | Approximate response rate (%) |
|---|---|---|
| DairySA | No responses | 0 |
| DairyNSW | No responses | 0 |
| NORCO | 6 | 3 |
| AusDairyL | 10 | 2 |
| Dairy Farmers Milk Co-operative | 23 | 10 |
| Scibus | 3 | 12 |
| South-Coast and Highlands Dairy Co-operative | 2 | 4 |
| Dairy farmers from elicitation questionnaire | 12 | 36 |
| Total | 56 | 3 |

In Section 1, the question ‘Who is primarily responsible for treating these lame cows?’ had one invalid response. The question, ‘What is your annual milk yield?’ had nine responses that appeared to be incorrect because the milk yield reported was too small for the reported herd size. These invalid responses were not included in the analyses. Therefore, these questions included 55 and 47 dairy farmer responses, respectively, while the remaining questions included 56 responses.

### 5.3.2. Farmer demographics and farm characteristics

The mean age of the dairy farmers was 48 years (range 22 - 69) (Table 5-6). Most respondents were male (n = 43, 77%). The mean number of years of experience with dairy cows was 31 (range 5 – 54). The median number of years managing the current dairy farm was 15 (range 1 - 50). The mean number of full time employees on the dairy farm was two (range 0 - 6). Mean herd size was 289 dairy cows per farm (range 70 – 1,020) with a mean annual milk production of 1,888,919 L (range 275,000 – 6,300,000 L). The most common breeds of dairy cows kept on each farm were Holstein Friesian (n = 54, 96%), Holstein x Jersey (n = 28, 50%), and Jersey (n = 26, 46%) (Table 5-7). Most farms applied pasture-based feeding in combination with grain feeding at the dairy (n = 38, 69%) and used a herringbone milking system (n = 42, 75%) (Table 5-7).

Table 5-6: Study population and farm characteristics for the 56 dairy farmers that completed the questionnaire.

| Variable | Mean (SD) | Median (IQR) | Range |
|---|---|---|---|
| Dairy farmer age (years) | 47.7 (10.6) | 49 (40, 55.5) | 22 – 69 |
| Years of experience with dairy cows | 30.8 (12) | 30 (23, 39.5) | 5, 54 |
| Years managing current dairy farm | 16.1 (11.2) | 15 (6, 25) | 1, 50 |
| Number of full time employees on farm | 2.1 (1.5) | 2 (1, 3) | 0, 6 |
| Number of milking cows in dairy herd | 289 (177.1) | 242.5 (182.5, 370) | 70, 1020 |
| Annual milk yield* (L) | 1,888,919 (1,259,391) | 1,550,000 (1,120,000, 2,500,000) | 275,000, 6,300,0000 |

*9 dairy farmers not included in analysis because their responses did not make sense.

Table 5-7: Frequency table of the number and breeds of dairy cows kept on each farm and the feeding and milking systems used on each farm (n = 56 dairy farmers).

| Question | Frequency (%) |
|---|---|
| What breed(s) of cow(s) do you keep? | |
| Holstein Friesian | 54 (96) |
| Jersey | 26 (46) |
| Holstein x Jersey | 28 (50) |
| Brown Swiss | 14 (25) |
| Ayrshire | 6 (11) |
| Other | 18 (32) |
| What is the predominant feeding system used for your dairy herd? | |
| Total Mixed Ration | 3 (5) |
| Pasture based and grain feeding at the dairy | 38 (69) |
| Partial mixed ration | 8 (14) |
| Pasture only | 7 (13) |
| What type of milking system do you use for your dairy herd? | |
| Automatic | 2 (4) |
| Rotary | 12 (21) |
| Herringbone | 42 (75) |

### 5.3.3. Lameness in dairy cows

The median incidence risk of lameness as reported by the dairy farmers was 5.9% (range 0 – 33.3). Forty-one per cent of the dairy farmers stated that the occurrence of lame cows in the past five years had remained the same (n = 23), while others stated that lameness had somewhat improved (n = 15, 27%), or had become much better (n = 13, 23%) (Table 5-8). Only 9% (n = 5) of the dairy farmers reported that the occurrence of lame cows in their dairy herd had become somewhat worse. In most cases, the farm manager was primarily responsible for the care of lame cows in the herd (n = 39, 70%). Thirty-four percent (n = 19) of the dairy farmers reported that they did not observe a seasonal effect for the occurrence of lame cows. For those dairy farmers that did, most observed lameness in winter (n = 16, 29%) or spring (n = 12, 21%).

Of the management practices listed in the questionnaire, 46 (82%) of the dairy farmers stated that they investigate cows for foot lesions immediately upon noticing they are lame, 34 (61%) regularly repair track surfaces, and 18 (32%) use a dietary supplement to strengthen the hoof structure (Table 5-9). Only 10 (18%) and 7 (13%) dairy farmers said that they use a locomotion scoring system daily to screen for lame cows or conduct maintenance hoof trimming twice per year, respectively.

Table 5-8: Frequency distribution of the dairy farmer reported prevalence of lame cows in past 5 years, the individual/s primarily responsible for care of lame cows and whether dairy farmers observed a seasonal effect for the occurrence of lameness in their herds (n = 56 dairy farmers).

| Question | Frequency (%) |
|---|---|
| Over the past five years, has the occurrence of lame cows on your farm become | |
| Much worse | 0 |
| Somewhat worse | 5 (9) |
| Remained the same | 23 (41) |
| Somewhat improved | 15 (27) |
| Become much better | 13 (23) |
| Who is primarily responsible for treating these lame cows? | |
| Veterinarian | 10 (18) |
| Farm manager | 39 (70) |
| Farm manager and farm workers | 3 (5) |
| Share farmer | 1 (2) |
| Farm workers | 2 (4) |
| Do you observe a seasonal effect for lame cows, if yes, what season? | |
| No effect | 19 (34) |
| Winter | 16 (29) |
| Spring | 12 21) |
| Summer | 3 (5) |
| Autumn | 6 (11) |

Table 5-9: Management practices that the dairy farmers (n = 56) indicated that they currently use routinely on their dairy farm (dairy farmers were able to tick all applicable options).

| Management practice | Frequency (%) |
|---|---|
| Conduct maintenance hoof trimming twice per year, i.e., every 6 months | 7 (12) |
| Use a locomotion scoring system daily, before or after milking, to screen for lame cows | 10 (17) |
| Investigate a lame cow for foot lesions immediately upon noticing it is lame | 47 (81) |
| Fund staff attendance to relevant workshops | 7 (12) |
| Regularly repair track surfaces particularly after heavy rainfall (i.e. removal of sharp rocks and/or slurry) | 34 (59) |
| Use a dietary supplement, such as biotin, to strengthen the hoof structure | 18 (31) |
| None of the above | 6 (10) |
| Other | 7 (12) |

### 5.3.4. Dairy farmer intentions

The overall intention of the dairy farmers to make improvements to their management practices of foot lesions in the next year was moderate (mean = 4.8) (Table 5-10). Compared to the total population, intention was significantly different between young and old ($p<0.001$) and male and female ($p<0.001$) dairy farmers. The probability of an observation for the groups ‘young’ and ‘male’ dairy farmers having a true value that was higher than an observation in the groups ‘old’ and ‘female’ dairy farmers was 77 and 22%, respectively. There was no difference between high and low producing or large and small dairy farms. This resulted in four sub-populations of dairy farmers: young, older, male and female. Intention was highest for female and young dairy farmers, respectively. For the total study population and the four sub-groups of dairy farmers, the median and interquartile range of the statements used to measure intention are presented in Table 10 and the distribution of scores for each statement are presented in Appendix 29.

Less than half (n = 24, 43%) of the total study population gave a five or higher for all three intention statements, while four (7%) dairy farmers gave a three or lower for all three intention statements. Only five farmers (9%) gave a seven for all three intention statements. The intention statement for which most farmers (n = 34, 61%) gave a five or higher was ‘I will try to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months’. Six (11%) dairy farmers gave a three or lower for this statement, while 17 (30%) gave a score of 4. For the other two intention statements, (‘I plan to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months’ and ‘I intend to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months’), 29 (52%) and 28 (50%)

dairy farmers gave a five or higher; 10 (18%) and 11 (19%) gave a three or lower; and, 17 (30%) and 16 (29%) gave a score of four, respectively.

Table 5-10: Median, inter-quartile range (IQR) and overall mean score using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response) for the three statements used to measure the intention of all dairy farmers (n = 56), and the four sub-populations, young (n = 38), old (n = 18), male (n = 43), and female (n = 13) dairy farmers to make improvements to their management practices of foot lesions causing lameness in dairy cows.

| Intention statement | All dairy farmers median (IQR) | Young dairy farmers median (IQR) | Old dairy farmers median (IQR) | Male dairy farmers median (IQR) | Female dairy farmers median (IQR) |
|---|---|---|---|---|---|
| I plan to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months. | 5 (4, 6) | 5 (4, 6) | 4 (3, 4) | 4 (4, 6) | 6 (5, 7) |
| I intend to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months | 5 (4, 6) | 5 (4, 6) | 4 (3, 4) | 4 (4, 5) | 5 (5, 7) |
| I will try to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months | 5 (4, 6) | 5 (4, 6) | 4 (3, 4) | 5 (4, 6) | 6 (5, 7) |
| Overall intention score | 4.8 | 5.2 | 4 | 4.3 | 5.7 |

### 5.3.5. Direct measures

#### *Direct attitude*

Cronbach's alpha coefficient for the three statements was higher than 0.60 (Table 5-11), therefore it was appropriate to use the mean value as a summary measure for the construct. The overall attitude of the dairy farmers to make improvements to their management practices of foot lesions in the next year was moderate (mean = 5.1) and was significantly correlated with intention ($r_s$ 0.69, p:<0.001). Therefore, there was sufficient evidence to accept hypothesis H7a: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the direct measure of their attitude.

The median, interquartile range and correlation with intention of the statements for direct attitude are presented in Table 5-11. The distribution of scores for each statement are presented in Appendix 30. Most dairy farmers (n = 44, 79%) had a positive attitude (giving a score of $\geq 5$) toward the items 'For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be bad/good' (i.e., 79% of dairy farmers thought that making improvements to their current management practices of foot lesions in their dairy herd in the next 12 months would be good) and ‘For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be useless/useful’ (n = 46, 82%). However, less than half of the dairy farmers (n = 22, 39%) had a positive attitude toward the item ‘For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be difficult/easy’ with 18 (32%) dairy farmers indicating that it would be difficult. Twenty-one dairy farmers (38%) gave a five or higher and four farmers (7%) gave a seven for all three direct attitude items. The three statements were significantly correlated with intention (range: $r_s$ 0.45 – 0.64).

Scatterplots for overall direct attitude and the three statements are presented in Appendix 31. The scatterplots show that some dairy farmer responses were inconsistent with the theory. While the tenants of the theory suggest that the stronger the attitude, the stronger the intention, the plots demonstrate that some individuals have strong intentions but weak attitudes or vice versa. This has resulted in substantial scatter in the plots, particularly Figure 8.3 (Appendix 31).

Table 5-11: Median, inter-quartile range (IQR), overall mean value, correlation with intention and Cronbach’s alpha, for the three statements used to measure the construct direct attitude using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response).

| Direct attitude statement | Median (IQR) | Correlation with intention |
|---|---|---|
| For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be bad/good | 6 (5, 7) | 0.64** |
| For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be difficult/easy | 4 (3, 5) | 0.45** |
| For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be useless/useful | 5 (5, 6) | 0.64** |
| Cronbach's alpha 0.70 | | |
| Overall direct attitude score 5.1 | | 0.69 ** |

** P < 0.01

### *Direct Subjective Norm*

Cronbach’s alpha coefficient for the three statements was higher than 0.60 (Table 5-12), therefore it was appropriate to use the mean value as a summary measure for the construct. The overall subjective norm of the dairy farmers to make improvements to their management practices of foot lesions in the next year was moderate (mean = 4.6) and was significantly correlated with intention ($r_s$ 0.63, p:<0.001). Therefore, there was sufficient evidence to accept hypothesis H8a: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the direct measure of their subjective norm.

The median, interquartile range and correlation with intention of the statements for direct subjective norm are presented in Table 5-12. The distribution of scores for each item are presented in Appendix 30. Most dairy farmers (n = 44, 79%) had a positive attitude (giving a score of $\geq 5$) toward the items ‘For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be bad/good’ (i.e., 79% of dairy farmers thought that making improvements to their current management practices of foot lesions in their dairy herd in the next 12 months would be good) and ‘For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be useless/useful’ (n = 46, 82%). However, less than half of the dairy farmers (n = 22, 39%) had a positive attitude toward the item ‘For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be difficult/easy’ with 18 (32%) dairy farmers indicating that it would be difficult. Twenty-one dairy farmers (38%) gave a five or higher and four farmers (7%) gave a seven for all three direct attitude items. The three statements were significantly correlated with intention (range: $r_s$ 0.42 – 0.70).

Scatterplots for overall direct subjective norm and the three statements are presented in Appendix 32. Figures 8.7 and 8.8 (Appendix 32) show that some dairy farmer responses were inconsistent with the theory. While the tenants of the theory suggest that the stronger the subjective norm, the stronger the intention, the plots demonstrate that some individuals have strong intentions but weak subjective norm or vice versa. This has resulted in substantial scatter in these plots.

Table 5-12: Median, inter-quartile range (IQR), overall mean value, correlation with intention and Cronbach's alpha, for the three statements used to measure the construct direct subjective norm using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response).

| Direct subjective norm statement | Median (IQR) | Correlation with intention |
|---|---|---|
| Individuals who are important to me would make improvements to their current management practices of foot lesions in their dairy herd in the next 12 months | 4 (4, 6) | 0.49** |
| Individuals whose views are important to me would approve if I made improvements to my current management practices of foot lesions in my dairy herd in the next 12 months | 5 (4, 6) | 0.70** |
| Individuals who are important to me would think that I should make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months | 4 (3, 5) | 0.42** |
| Cronbach's alpha 0.72 | | |
| Overall direct subjective norm score 4.6 | | 0.63** |

** P < 0.01.

### *Direct Perceived Behavioural Control*

Cronbach's alpha coefficient for the two statements was lower than 0.60 (Table 5-13). Therefore, it was not appropriate to use the mean value as a summary measure for the construct or to test its correlation with intention (i.e., hypothesis H9a).

The median, interquartile range and correlation with intention of the statements for direct perceived behavioural control are presented in Table 5-13. The distribution of scores for each item are presented in Appendix 30. Most dairy farmers indicated feeling in control for both statements used to measure the construct ('How much control do you believe you have over the decision to make improvements to your current management practices of foot lesions in your dairy herd in the next 12 months', n = 43, 77%, and 'I am confident that I could make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months if I wanted to' n = 32, 57%). Twenty-nine (52%) and six (10%) dairy farmers gave a five or higher or a seven for both statements, respectively. Only the statement 'I am confident that I could make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months if I wanted to' was significantly correlated with intention (0.43, p:<0.001).

A scatterplot for this statement is presented in Appendix 33. This scatterplot shows that some dairy farmer responses were inconsistent with the theory. While the tenants of the theory suggest that the stronger the perceived behavioural control, the stronger the intention, the plot demonstrate that some individuals have strong intentions but weak perceived behavioural control or vice versa. This has resulted in substantial scatter in the plot.

Table 5-13: Median, inter-quartile range (IQR), overall mean value, correlation with intention and Cronbach's alpha, for the three statements used to measure the construct direct perceived behavioural control using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response).

| Direct perceived behavioural control statement | Median (IQR) | Correlation with intention |
|---|---|---|
| How much control do you believe you have over the decision to make improvements to your current management practices of foot lesions in your dairy herd in the next 12 months? | 6 (5, 7) | NS |
| I am confident that I could make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months if I wanted to. | 5 (4, 6) | 0.43** |
| Cronbach's alpha 0.39 | | |

** P < 0.01.

### 5.3.6. Correlations between direct and indirect constructs

The correlation between direct and indirect attitude was strong and significant ($r_s$0.72, p<0.001) while the correlation between direct and indirect subjective norm was moderate and significant (rs0.57, p<0.001). Therefore, there was sufficient evidence to accept hypotheses H4 and H5 and it was appropriate to substitute the direct constructs with the indirect counterpart. Because it was not appropriate to determine an overall summary measure for direct perceived behavioural control, it was not possible to test the correlation between direct and indirect perceived behavioural control (i.e., hypothesis H6). Consequently, it was not possible to test hypothesis 9b (The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the indirect measures of their perceived behavioural control).

### 5.3.7. Indirect measures

The sample sizes for the four sub-populations of dairy farmers were relatively small. Therefore, only descriptive analyses (median, interquartile range, and overall mean value) for these sub-populations were performed. Correlations were not considered.

#### *Indirect attitude*

The median, interquartile range, and overall mean value of the statements for indirect attitude are presented in Table 5-14. Correlations are included for the total study population. The overall indirect attitude of the dairy farmers to make improvements to their management practices of foot lesions in the next year was moderate (overall mean = 15) and significantly correlated with intention ($r_s$ 0.65, p:<0.001). Therefore, there was sufficient evidence to accept hypothesis H7b: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the indirect measure of their attitude. Indirect attitude was highest for female and young dairy farmers, respectively.

All three statements (behavioural beliefs) were significantly correlated with intention (Table 5-14). Therefore, there was sufficient evidence to accept hypothesis H1: Each individual behavioural belief is significantly correlated with dairy farmer intentions to make improvements to their current management practices of foot lesions.

The distribution of scores for each item is presented in Appendix 34. Most dairy farmers had a positive attitude (giving a score of score ≥ 5) toward the items 'Improving my current management practices of foot lesions will improve the welfare of my dairy cows' (n = 40, 71%) and 'If I improve my current management practices of foot lesions, milk production of my herd will increase' (n = 37, 66%). Less than half of the dairy farmers indicated that making improvements to their current management practices of foot lesions in their dairy herd would be worth the potential cost involved (n = 25, 44%), with 32% (n = 18) indicating that it would not be worth the potential cost involved. Twenty dairy farmers (36%) gave a five or higher and four dairy farmers (7%) gave a seven for all three indirect attitude items.

Scatterplots for overall indirect attitude and the three statements are presented in Appendix 35. The scatterplots for the three statements show that some dairy farmer responses were inconsistent with the theory. While the tenants of the theory suggest that the stronger the behavioural belief, the stronger the intention, the plots demonstrate that some individuals have strong intentions but weak behavioural beliefs or vice versa. This has resulted in substantial scatter in the plots.

Table 5-14: Median, inter-quartile range (IQR), and overall mean using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response) for the three statements used to measure the indirect attitude of all dairy farmers (n = 56), and young (n = 38), old (n = 18), male (n = 43), and female (n = 13) dairy farmers to make improvements to their management practices of foot lesions causing lameness in dairy cows.

| Indirect attitude statement | All farmers (IQR) | Correlation with intention | Median (IQR) Young dairy farmers | Median (IQR) Old dairy farmers | Median (IQR) Male dairy farmers | Median (IQR) Female dairy farmers |
|---|---|---|---|---|---|---|
| Improving my current management practices of foot lesions will improve the welfare of my dairy cows | 5 (4, 7) | 0.59** | 6 (5, 7) | 5 (4, 6) | 5 (4, 6) | 6 (5, 7) |
| If I improve my current management practices of foot lesions, milk production of my herd will increase. | 5 (4, 7) | 0.59** | 6 (4, 7) | 5 (4, 6) | 5 (4, 5) | 7 (5, 7) |
| Making improvements to my current management practices of foot lesions in my dairy herd will not be worth the potential cost involved. | 4 (3, 6) | 0.41** | 4 (3, 6) | 4 (3, 5) | 4 (3, 5) | 5 (4, 6) |
| Overall indirect attitude (∑(bs) - range 3 to 21) (mean) | 15 | 0.65** | 15.18 | 14 | 14 | 19 |

* P < 0.05, ** P < 0.01.

### *Indirect subjective norm*

The median, interquartile range, and overall mean value of the statements for indirect attitude are presented in Table 5-15. Correlations are included for the total study population. Overall the dairy farmers indicated that they perceived strong social pressure to make improvements to their management practices of foot lesions causing lameness (overall mean = 16). Indirect subjective norm was significantly correlated with intention ($r_s$ = 0.57, p:<0.001). Therefore, there was sufficient evidence to accept hypothesis H8b: The intention of dairy farmers to make improvements to their current management practices of foot lesions is significantly correlated with the indirect measures of their subjective norm. Indirect subjective norm was highest for female and young dairy farmers, respectively.

All three statements (normative beliefs) were significantly correlated with intention (Table 5-15). Therefore, there was sufficient evidence to accept hypothesis H2: Each individual normative belief is significantly correlated with dairy farmer intentions to make improvements to their current management practices of foot lesions.

The distribution of scores for each item is presented in Appendix 34. All three normative referents (consumers, staff members and animal welfare groups) were considered important. For consumers, staff members and animal welfare groups, 36 (64%), 37 (66%) and 45 (80%) dairy farmers gave a five or higher; while 18 (32%), 17 (30%) and 16 (28%) gave a score of four. Twenty-five (45%) of farmers gave a five or higher for all three referents and only four (7%) farmers gave a seven for all three referents.

Scatterplots for overall indirect subjective norm and the three statements are presented in Appendix 36. The scatterplots for the three statements show that some dairy farmer responses were inconsistent with the theory. While the tenants of the theory suggest that the stronger the normative belief, the stronger the intention, the plots demonstrate that some individuals have strong intentions but weak normative beliefs or vice versa.

Table 5-15: Median, inter-quartile range (IQR), and overall mean using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response) for the three statements used to measure the indirect subjective norm of all dairy farmers (n = 56), and young (n = 38), old (n = 18), male (n = 43), and female (n = 13) dairy farmers to make improvements to their management practices of foot lesions causing lameness in dairy cows.

| Indirect subjective norm statement | All farmers (IQR) | Correlation with intention | Median (IQR) Young dairy farmers | Median (IQR) Old dairy farmers | Median (IQR) Male dairy farmers | Median (IQR) Female dairy farmers |
|---|---|---|---|---|---|---|
| Consumers of dairy products would think that I should not/ I should improve my current management practices of foot lesions in my dairy cows. | 5 (4, 7) | 0.38** | 6 (5, 7) | 5 (4, 7) | 5 (4, 6) | 7 (5, 7) |
| My staff members would disapprove/approve if I improved my current management practices of foot lesions in my dairy cows. | 5 (4, 7) | 0.64** | 6 (4, 7) | 4 (4, 5) | 5 (4, 6) | 6 (5, 7) |
| Animal welfare groups would disapprove/ approve if I improved my current management practices of foot lesions in my dairy cows. | 6 (5, 7) | 0.36** | 6 (5, 7) | 5 (4, 7) | 6 (4, 7) | 6 (6, 7) |
| Overall indirect subjective norm (∑(ns) - range 3 to 21) | 16 | 0.57** | 16.5 | 14 | 15 | 19 |

* P < 0.05, ** P < 0.01.

### *Indirect Perceived Behavioural Control*

It was not appropriate to use the overall mean as a summary measure of the construct indirect perceived behavioural control because the construct could not be validated against its direct counterpart. The median, and interquartile range of the statements for indirect attitude are presented in Table 5-16. Correlations are included for the total study population. All three statements (control beliefs) were significantly correlated with intention. Therefore, there was sufficient evidence to accept hypothesis H3: Each individual control belief is significantly correlated with dairy farmer intentions to make improvements to their current management practices of foot lesions.

The distribution of scores for each item is presented in Appendix 34. The control belief for which most dairy farmers (77%) gave a five or higher was ‘If the benefits of implementing practices outweigh the costs I would be less likely/ more likely to improve my current management practices of foot lesions in my dairy cows’. Seventeen (30%) of the dairy farmers gave a score of four for this statement. For the statements ‘Having better knowledge and training would make it more difficult/easier to improve my current management practices of foot lesions in my dairy cows’, and ‘Having better equipment and facilities available would make it easier to improve my current management practices of foot lesions in my dairy herd’ 42 (75%) and 39 (69%) of dairy farmers gave a 5 or higher, while 17 (30%) and 15 (27%) gave a score of four. Thirty-one (55%) dairy farmers gave a five or higher and seven (13%) dairy farmers gave a seven for all three statements.

Scatterplots for the three statements are presented in Appendix 37. The scatterplots for the three statements show that some dairy farmer responses were inconsistent with the theory. While the tenants of the theory suggest that the stronger the normative belief, the stronger the intention, the plots demonstrate that some individuals have weak intentions but strong control beliefs.

Table 5-16: Median, inter-quartile range (IQR), and overall mean using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response) for the three statements used to measure the indirect perceived behavioural control of all dairy farmers (n = 56), and young (n = 38), old (n = 18), male (n = 43), and female (n = 13) dairy farmers to make improvements to their management practices of foot lesions causing lameness in dairy cows.

| Indirect perceived behavioural control | All farmers (IQR) | Correlation with intention | Median (IQR) Young dairy farmers | Median (IQR) Old dairy farmers | Median (IQR) Male dairy farmers | Median (IQR) Female dairy farmers |
|---|---|---|---|---|---|---|
| Having better equipment and facilities available would make it more difficult/easier to improve my current management practices of foot lesions in my dairy herd. | 6 (4, 7) | 0.27* | 6 (5, 7) | 5 (4, 6) | 6 (4, 7) | 6 (5, 7) |
| If the benefits of implementing practices outweigh the costs I would be less likely/ more likely to improve my current management practices of foot lesions in my dairy cows. | 5 (5, 7) | 0.35** | 6 (5, 7) | 6 (4, 6) | 6 (4, 6) | 5 (5, 7) |
| Having better knowledge and training would make it more difficult/easier to improve my current management practices of foot lesions in my dairy cows. | 5 (4, 6) | 0.47** | 5.5 (4, 7) | 5 (4, 5) | 5 (4, 6) | 6 (5, 7) |

* P < 0.05, ** P < 0.01.

### 5.3.8. Summary of results

Overall the dairy farmers demonstrated moderate intention to make improvements to their current management practices of foot lesions causing lameness in their dairy cows. Intention was stronger for female and younger dairy farmers. All of the behavioural, normative and control beliefs investigated were associated with intention and therefore act as potential cognitive drivers to strengthen dairy farmer intentions (Figure 5-4). Of the constructs direct and indirect attitude and direct and indirect subjective norm, direct attitude demonstrated the strongest association with intention, followed by indirect attitude. It was not possible to test the correlation between direct and indirect perceived behavioural control, nor the correlation between each of these constructs and intention.

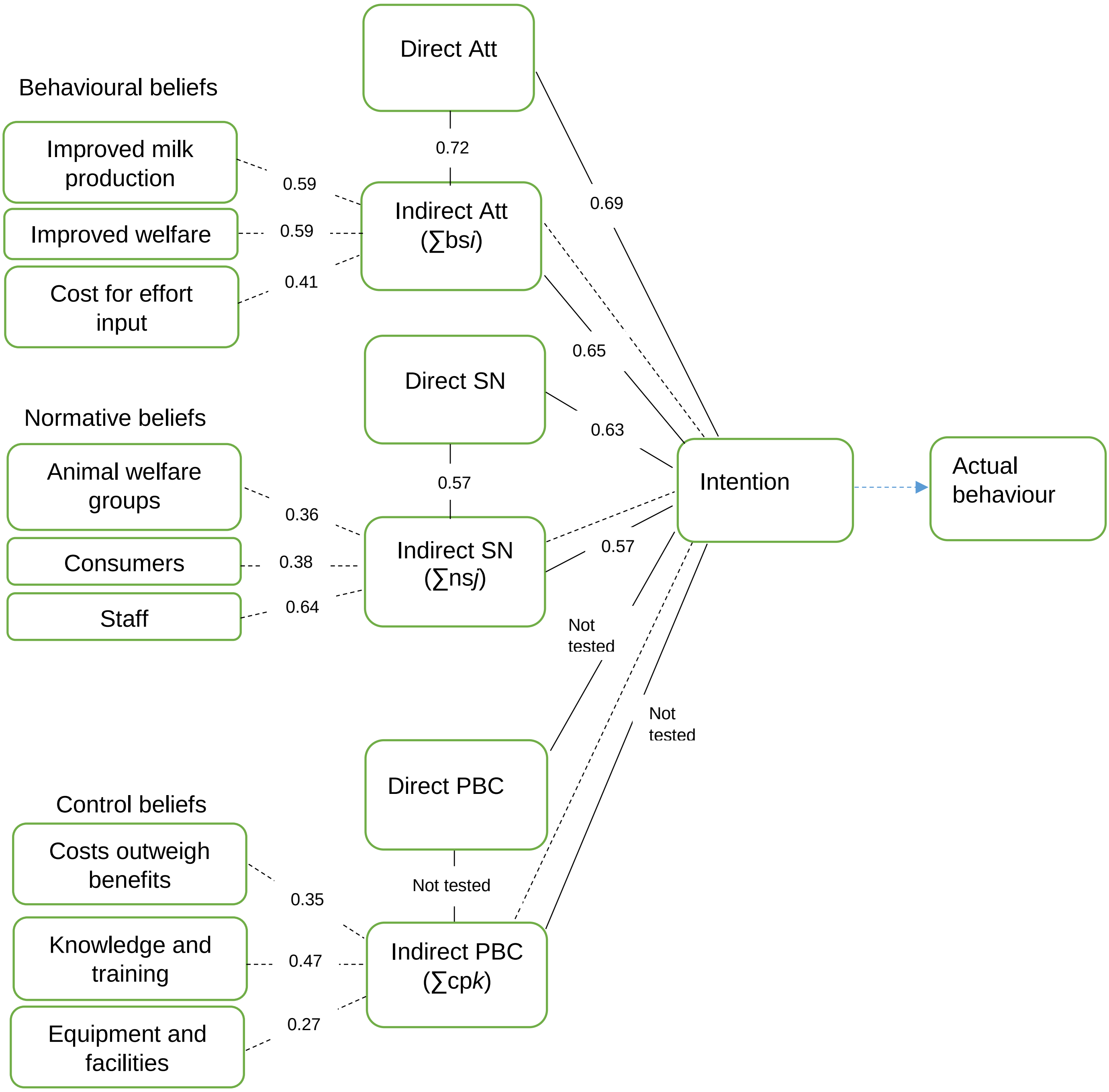


Figure 5-4: Spearman rank correlation coefficients for the proposed hypotheses. Att: attitude, SN: subjective norm, PBC: perceived behavioural control.

## 5.4. Discussion

This study identified important cognitive drivers that have the potential to improve dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness in their dairy cows. Of the constructs assessed, direct and indirect attitude demonstrated the strongest associations with intention. The implications of these findings are discussed followed by the limitations of this study.

### 5.4.1. Intention

Overall, the dairy farmers demonstrated a moderate intention to make improvements to their current management practices of foot lesions causing lameness. There are two major explanations for the moderate intention. First, the dairy farmers may feel that their current management of foot lesions is adequate as most (n = 50, 89%) indicated that they were already implementing at least one of the suggested management practices.

Second, the dairy farmers may not perceive foot lesions causing lameness to be a priority in their herds and therefore have limited drive to make changes to their current management practices. Evidence contributing to this exists in this study where the incidence risk of lameness as estimated by the dairy farmers was relatively low with 73% (n = 41) suggesting that 10% or less of their herd was lame annually. Whether these estimates are correct or not is unknown. Whether these estimates are correct or not is unknown. However, the literature provides evidence to suggest that dairy farmers underestimate the prevalence of lameness in their herds by 8 – 25% (Wells et al. 1993; Espejo et al. 2006; Leach et al. 2010). The potential underestimation of lameness made by these dairy farmers may result in failure to realise the true magnitude of the problem.

While demographic and other background factors are assumed to have no direct effect on intention, Ajzen and Fishbein (1969) suggests that they will be related if they have influence on the underlying behavioural, normative and control beliefs (Ajzen 1985). In this study, while farmer intention did not differ between farmers with different levels of milk production or different farm sizes, (indicating that these factors are likely to be irrelevant in contributing to dairy farmer intentions) female and younger dairy farmers were found to have stronger intentions than their respective counterparts. For the three intention statements, only 23 – 34% of the older and 40 – 52% of male dairy farmers gave a score of 5 or greater. This is in comparison to 64 – 74% of younger and 72 – 92% of female dairy farmers giving a score of five or greater, suggesting that older and male dairy farmers are more resistant towards making changes in their current management practices. This resistance may be attributed to habit (to keep doing things as they have always done), past experience (where previous changes may have resulted in no improvement) or a less progressive nature in general. Garforth et al. (2006) similarly reported differences between young and old dairy farmers with older dairy farmers expressing more negative views towards using techniques for improving oestrus detection. Conversely, Bruijnis et al. (2013) reported no difference in intentions between young and old or male and female dairy farmers. However, the mean age obtained by Bruijnis et al. (2013) (45 years) was much younger than the age obtained in this study (53 years), therefore these studies are not directly comparable. Further Bruijnis et al. (2013) do not report the ratio of young and old dairy farmers, merely stating that both young and old dairy farmers participated in questionnaire. Therefore, it is not possible to determine whether the sample sizes of young and old farmers were large enough to detect a difference.

### 5.4.2. Dairy farmer beliefs

Overall, intention was significantly and positively associated with all of the behavioural, normative and control beliefs investigated. Therefore, all of these beliefs are considered as potential drivers to strengthen dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness.

#### *Behavioural beliefs*

Of the three behavioural beliefs, the beliefs that improving current management practices of foot lesions would improve animal welfare and increase milk production demonstrated the strongest association with intention. Bruijnis et al. (2013) similarly found that improving dairy cow welfare and increased milk production were important drivers for improving dairy cow foot health; however, the associations were lower than those found in this study ($r_s$ 0.33 and 0.18, respectively). The association between intention and the belief that improving current management practices of foot lesions would be worth the potential cost involved was moderate at best. Therefore, cost may be a potential barrier for some dairy farmers. This is supported by Bruijnis et al. (2013) who reported a relatively weak correlation ($r_s$ 0.27) for ‘Improving dairy cow foot health can be achieved with cost effective measures’.

Some responses from the dairy farmers were inconsistent with the theory. There are a number of potential explanations for these results. First, since the beliefs held by an individual represent the knowledge they have, the relative weights of the beliefs are likely to vary from one person to another. For example, in Figure 8.13 (Appendix 35), one individual shows strong intention, but their belief that making improvements would be worth the potential cost involved is weak. This may indicate that this dairy farmer does not hold this as a salient belief, possibly because they lack knowledge associated with the cost of lameness. Alternatively, other beliefs not assessed in this study may be more salient for this individual, therefore they may have high intention, but not based on this particular belief. This study only included the three most frequently mentioned behavioural beliefs from the elicitation study. Therefore, it is possible that not all of the salient behavioural beliefs of the target population have been included. Second, according to (Ajzen 2018) it is possible for the elicited beliefs to be inconsistent with each other and with the overall direction of their attitude and therefore intention. Finally, the individual may have simply misinterpreted the statement and the scores provided do not reflect their true intention or beliefs.

### *Normative beliefs*

Of the normative beliefs (important referents), dairy farmers perceived staff members to apply the strongest social pressure on their intention to make improvements to their current management practices of foot lesions causing lameness in their dairy cows. The dairy farmers perceived weaker social pressure from consumers and animal welfare groups. This suggests that overall, the dairy farmers may perceive greater social pressure to make improvements to their current management practices from those who are closer to them. This was also found to be the case by Borges et al. (2014) who studied farmer intentions to adopt improved natural grassland, finding that farmers perceived the most social pressure from family and friends and is consistent with research demonstrating that individuals are influenced more by those who are similar to themselves than those who are not (Cialdini & Goldstein 2004). Garforth et al. (2006) also demonstrated that dairy farmers perceived social pressure from colleagues. However, other dairy farmers and the veterinarian were associated with stronger social pressure. Conversely, Bruijnis et al. (2013) found that dairy farmers felt the most social pressure from those referents more removed from their day to day life (i.e., the feed advisor and foot trimmer) and that they felt less social pressure from family, friends and colleagues. While family, other farmers and the veterinarian were identified as important referents in the elicitation questionnaire of this study, due to questionnaire size restrictions, their influence was not tested in the final questionnaire.

Several dairy farmers indicated that they neither experience social pressure or a lack of social pressure from the important referents (i.e., chose neutral to score their normative belief). There are three potential explanations for this. First, this may indicate that the dairy farmers did not know what views the important referents would take. Second, these statements ask individuals the level of social influence they feel. Therefore, their responses may be susceptible to social desirability bias, where being influenced by others is perceived as socially unacceptable (French et al. 2007). Finally, the dairy farmers may not have understood the statement and therefore select neutral, opposed to indicating a strong or weak influence (Darker & French 2009). Some responses from the dairy farmers where inconsistent with the theory. These responses may be explained as for behavioural beliefs.

#### *Control beliefs*

Of the three control beliefs, the belief that having better knowledge and training would enable dairy farmers to make improvements to their management practices demonstrated the strongest association with intention. Weak associations were found for ‘If the benefits outweigh the costs’ and ‘Having better equipment and facilities’. This reiterates that cost may be a potential barrier for some dairy farmers. Because the belief regarding equipment and facilities indicates financial implications cognitive dissonance may play a role, where although the dairy farmer may consider that better equipment and facilities could improve their management of foot lesions, they would rather not make the financial investment, and so remain content with their current management practices. Some responses from the dairy farmers where inconsistent with the theory. These responses may be explained as for behavioural beliefs.

### 5.4.3. Attitude, subjective norm and perceived behavioural control

The constructs direct and indirect attitude and direct and indirect subjective norm were significantly and positively associated with intention. This indicates that both the dairy farmers conscious and unconscious attitude and the perceived social pressure and opinions of important others are associated with their decision to make improvements to their current management practices of foot lesions. Direct and indirect attitude demonstrated the strongest associations, suggesting that dairy farmer attitudes may have more influence on their decision to make improvements than perceived social pressure and the opinions of others. Direct attitude demonstrated a stronger association with intention than indirect attitude. However, this association was only marginally stronger suggesting that dairy farmers intentions may be based on both their general feelings about whether making improvements would be good (or bad), easy (or difficult) or useful (or useless) and an assessment of the advantages and disadvantages of making improvements.

Due to the issues surrounding social desirability bias, it is not possible to ascertain whether the true extent of social pressure has been identified in this study. Nonetheless, direct subjective norm demonstrated a strong association with intention while that of indirect subjective norm was moderate. This suggests that dairy farmers intentions may be based more on perceived social pressure in general, rather than considering the opinions of specific individuals. However, the direct items demonstrate that while the dairy farmers indicated strongly that important others would approve of them making improvements, important others are less likely to think that the dairy farmers should make improvements. This suggests that perceived peer pressure may be low and dairy farmers may be discouraged in their intent to make improvements.

While it was not possible to investigate the association between direct or indirect perceived behavioural control with intention, the statements used to measure each construct provide some insight into the level of volitional control dairy farmers perceive they have in relation to making improvement a to their current management practices. The statement ‘How much control do you believe you have over the decision to make improvements to your current management practices of foot lesions in your dairy herd in the next 12 months?’ was not significantly correlated with intention. This suggests that the dairy farmers believe they have full control over making improvements to their management practices (i.e., if the dairy farmer decides not to make improvements to their management practices, it is because they lack the intention and not because of the presence of any constraining factor/s). This is reflected in the response to the statement as 75% of the dairy farmers indicated that they had moderate to very strong control over the decision to make improvements. Conversely, the statement ‘I am confident that I could make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months if I wanted to’, was significantly correlated with intention, indicating the presence of factors not within their control that may facilitate or constrain their decision to make improvements. The indirect statements provide evidence of constraining factors as most dairy farmers indicated that it would be easier and they would be more likely to make improvements if they had better equipment and facilities, better knowledge and training and if the benefits outweighed the costs. This suggest that the dairy farmers may require more resources and skills and that the intention to make improvements is indeed under non-volitional control.

### 5.4.4. Study limitations

There were a number of limitations identified in this study. First, while efforts were made to increase the questionnaire response rate (e.g., dissemination via multiple dairy organisations and repeat circulation via these organisation) the study population obtained was relatively small. In some cases, this may have been due the organisations having had their own or other questionnaires around the same time, resulting in respondent fatigue, where farmers simply did not want to or did not have the time for another questionnaire.

Second, due to the small study sample it was not possible to quantify the extent that direct and indirect attitude, direct and indirect subjective norm and the individual behavioural, normative and control beliefs contribute to dairy farmer intentions to make improvements to their management practices of foot lesions causing lameness in their dairy herds. To achieve this aim, more advanced statistical analyses such as logistic regression or structural equation modelling are required. Therefore, the relative importance that each construct and belief may contribute to dairy farmer intentions was only able to be inferred from the correlation of each construct with intention.

Third, although the study sample appears to be a representative sample of Australian dairy farms as mean herd size, annual milk production, dominant breed and feeding system align with data reported by Dairy Australia (2016), the sample may be biased in terms of the dairy farmers. The extent of this potential bias is difficult to discern as demographic data specific to Australian dairy farm managers were difficult to obtain. However, the average age of dairy farm managers reported by Dairy Australia (2017) was 54 years; slightly higher than the 48 years reported in this study. Using the average age of 54 years, 68% of the study population were classified as young (≤ 53). Therefore, our study population demonstrates a bias towards younger dairy farmers. This may be a consequence of the online format of the questionnaire, which may have affected the response rate as internet use has been demonstrated to be negatively associated with increasing age (Chesters et al. 2013). In terms of the results, the behavioural, normative and control beliefs demonstrating the stronger associations with intention may not be generalisable to the wider population of dairy farmers. Therefore, they may not represent the beliefs with the potential to have the greatest influence on dairy farmer intentions.

Fourth, the statements used to measure the construct direct perceived behavioural control did not achieve high internal consistency. While care was taken to construct these statements, direct statements have been shown to be more difficult for respondents to understand and interpret than indirect statements (Darker & French 2009), as discussed in Chapter 2, Section 5.4. Although direct attitude and direct subjective norm achieved high internal consistency, it is possible that the dairy farmers found the direct perceived behavioural control statements difficult to interpret. While the five dairy farmers who participated in the pilot questionnaire did not indicate any difficulty responding to these particular statements, it is possible that this was not enough feedback to sufficiently represent Australian dairy farm managers. In addition, the construct was only measured using two statements. This may have reduced the probability of meeting the required threshold for internal consistency because Cronbach's alpha is affected by the number of items in the test, where the smaller the number of items used in the test, the higher the probability of obtaining a lower alpha value (Tavakol & Dennick 2011). Consequently, it was not appropriate to test the correlation between direct and indirect perceived behavioural control, nor the correlations between each of these constructs with intention.

Fifth, cost was identified as a salient belief for both behavioural and control beliefs. To the author's knowledge there are no examples in the literature of the same belief being used for different constructs. Therefore, it was not possible to determine whether it was inappropriate to use cost for both behavioural and control beliefs. Given the construction of statements is very specific to the relevant construct, there is no evidence to suggest that this should detract from the results of this study; it simply reiterates the importance of cost to dairy farmers.

Finally, demographic data for the study population participating in the elicitation questionnaire were not collected, therefore it was not possible to determine if this sample was representative of the target population. Consequently, it is not possible to conclude whether the salient beliefs used in the questionnaire are generalisable to the wider population of dairy farm managers. As this study used only the three most frequently mentioned behavioural, normative and control beliefs, to counteract this, this study may have benefited from including a larger set of salient beliefs for each indirect construct.

Regardless of these limitations, the behavioural, normative and control beliefs identified in this study provide important information about key cognitive drivers that have the potential to influence dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness in their dairy herds.

### 5.4.5. Recommendations for industry

Using the TPB framework, the underlying behavioural, normative and control beliefs that may influence dairy farmer intentions to make improvements to their current management practices of foot lesions have been identified. These beliefs offer the dairy industry practical targets to utilise in the development of strategies to promote improved foot health of dairy cows.

The behavioural beliefs that making improvements would improve dairy cow welfare, increase milk production and would be worth the potential cost involved, represent factors that may encourage dairy farmers to make improvements to their current management practices of foot lesions causing lameness in their dairy herds. While cost may be perceived an issue for some dairy farmers, it might be possible to challenge this belief and increase intention by utilising the more favourable behavioural beliefs about improved welfare and increased milk production. For example, programs targeted to disseminate information about improving management practices of foot lesions could emphasise the detrimental effects to dairy cow welfare (e.g., premature culling (Booth et al. 2004)) which can incur financial loss, and the costs associated with reduced milk yield.

Consumers, staff and animal welfare groups were identified as the important others that may exert some degree of social pressure and could therefore be used to motivate dairy farmers to make improvements to their current management practices of foot lesions. Staff members may be the best channel of influence as they often have the ability to contribute to management decisions. Therefore, to increase dairy farmer intentions, industry bodies should disseminate information to both dairy farmers and their staff members. This is because if staff members have the same information as the dairy farmers making management decisions, they can not only have a role in information delivery but are more likely to support dairy farmers in their decisions to improve their current management practices of foot lesions causing lameness.

The following control beliefs represent factors that may encourage dairy farmers to make improvements to their current management practices of foot lesions causing lameness in their dairy herds: having better knowledge and training, when benefits outweigh costs, and having better equipment and facilities. Therefore, it is recommended that industry provide dairy farmers with more information and training opportunities about the management of foot lesions. This may help them to perceive greater control and therefore facilitate their intentions to improve their current management practices.

Costs incurred (and the inconvenience involved) in lameness control measures are important to dairy farmers. Despite the wide availability of estimates of the cost of cow lameness on farm incomes because of reduced milk production, premature culling, increased calving intervals, discarded milk, veterinary fees and increased labour use, many dairy farmers still question the cost: benefit ratio of lameness control measures. Dairy farmers acknowledge that lameness control measures can be less inconvenient than treating lame cows (Bennett et al. 2014).  They may be more willing to pay for lameness control measures that reduce the likelihood of undesirable lameness events thereby gaining advantages in convenience and animal welfare (and perhaps productivity) (Bennett et al. 2014).

While all of the beliefs are considered as potential drivers, the TPB analysis suggests that dairy farmer attitudes may have the strongest influence on their intentions to make improvements to their management practices. Therefore, in the first instance, it is recommended that strategies developed by industry to promote improved foot health of dairy cows focus on reinforcing the identified behavioural beliefs.

## 5.5. Conclusions

This study has provided the dairy industry guidance for potential targets in the development of strategies to promote improved foot health of dairy cows. While several beliefs were identified, those relating to attitude were determined to be the most pertinent. Therefore, in the first instance, industry should aim to strengthen the beliefs regarding improved animal welfare and increased milk production and challenge the belief regarding cost. The study population demonstrated a bias towards younger dairy farmers who may be more influenced by an alternate construct. Therefore, the behavioural beliefs may not be the most pertinent to the wider population of dairy farmers. However, they are the farmers of the future. Therefore, in future studies, focusing on younger dairy farmers is likely to have long term benefits.  Further research is necessary to validate the findings of this study.

# 6. Chapter 6: General Discussion and major conclusions

## 6.1. Introduction

This thesis consists of three studies aiming to provide the dairy industry with practical information to assist dairy farmers in improving their ability to identify foot lesions causing lameness in their dairy herds. In this chapter I link the key findings of these studies to the thesis aims and summarise the major conclusions including practical solutions for industry and recommendations for future research. Following this, I discuss the strengths and limitations of the studies.

## 6.2. Key findings

This thesis has identified three important problems for the dairy industry and investigates potential solutions. These are discussed here along with recommendations for further research.

### 6.2.1. Problems identified

First, while the systematic review (Chapter 3) identified a number of tests for the detection of lameness (observation of lameness indicators and observation of an arched back), foot lesions (infra-red thermography, LCS using a five-point scale and LCS using a force plate system) sole ulcers (investigation of various gait characteristics), and digital dermatitis (infra-red thermography, visual inspection in a milking parlour with swivelling mirror and powerful headlamp, visual inspection in a milking parlour and visual inspection in a milking parlour using a borescope), no tests for the diagnosis of specific foot lesions were identified.

Second, Chapter 4 demonstrated that a veterinarian and a dairy farmer achieved only poor to moderate agreement for suggested diagnosis and treatment of foot lesions occurring in a herd over a 12-month period. This suggests that dairy farmers may need assistance in the diagnosis and treatment of foot lesions causing lameness in their dairy herds. Given this, and the previous findings, it is pertinent that tools become available to assist dairy farmers for this purpose.

Finally, in Chapter 5, it was found that dairy farmers only have a moderate intention to make improvements to their management practices of foot lesions causing lameness in their dairy herds. This moderate intention may be due to the perception that lameness is not a priority problem in their herds and may have implications in future for the uptake of tests designed to assist dairy farmers in the diagnosis of foot lesions.

### 6.2.2. Potential solutions for industry

This thesis has presented the tele-foot-health system as a potential solution to address the first two problems previously identified. The tele-foot-health system is a novel tool that proposes to create a platform for improved diagnosis and treatment of foot lesions by dairy farmers. The tele-foot-health system can be thought of as a 'virtual on-farm consultant', using simple mobile phone technology whereby dairy farmers can take digital images of foot lesions and send them via multi-media message service to a remote veterinarian for prompt diagnosis and treatment. A pilot study (Chapter 4), demonstrated the potential success of this tool, where an on-site farm veterinarian and a remote veterinarian achieved relatively strong levels of agreement in the diagnosis and treatment of foot lesions occurring in a single dairy herd over a 12-month period. The tele-foot-health system has the potential to reduce welfare and economic implications associated with foot lesions in dairy cows.

To address the potential for successful uptake of the proposed tele-foot-health system and other possible diagnostic tools in future, Chapter 5 used the Theory of Planned Behaviour to investigate the underlying beliefs of dairy farmer intentions to make improvements to their current management practices of foot lesions. This study identified the following as the most salient beliefs of dairy farmers: improved animal welfare, increased milk production and that making improvements would be worth the cost involved (behavioural beliefs); the opinions of consumers, staff, and animal welfare groups are important in the decision to make improvements (normative beliefs); and having better equipment and facilities, improved knowledge and training, and a favourable cost benefit ratio are factors that would enable dairy farmers to make improvements (control beliefs). Each of these salient beliefs were found to be associated with dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness. According to the tenants of the theory, these beliefs have the potential to increase dairy farmer intentions to make improvements to their management practices. While all of the identified beliefs may be considered important, findings from this study suggest that the behavioural beliefs may have the greatest potential to facilitate positive behavioural change in dairy farmers. If these beliefs are applied to intervention campaigns and strategies directed at dairy farmers, these findings have the potential to improve the foot health of dairy cows in Australia. Therefore, the following strategies are recommended for industry:

Priority strategy

- Programs targeted to disseminate information about improving management practices of foot lesions should emphasise the detrimental effects of foot lesions to dairy cow welfare, the costs associated with reduced milk yield, and the potential financial gains when milk production is at optimal levels.

Other potential strategies

- Disseminate information regarding dairy cow foot health to both dairy farmers and their staff members.
- Provide dairy farmers with more information and training opportunities about the management of foot lesions.
- Provide dairy farmers with details about the specific costs associated with foot lesions. This should be comprehensive and include the costs associated with reduced milk production, increased labour, treatment, veterinarian consultations, increased calving interval, premature culling and discarded milk.

### 6.2.3. Recommendations for further research

- Further trials using the tele-foot-health system to validate its use and enhance application to Australian dairy herds by means of performing multi-farm trials using multiple farm workers, farm veterinarians and remote veterinarians across Australia. In doing this it will also be possible to i) assess intra- and inter-rater agreement to determine baseline levels of agreement between raters, and ii) develop a catalogue of the types and prevalence of lesions affecting Australian dairy herds.
- Disagreements between the farm veterinarian and remove veterinarian may be due to the different information they each receive, with the farm veterinarian having more information available. Therefore, it may be possible to improve diagnostic agreement by expanding the capacity of the tele-foot-health system to provide the remote veterinarian more information. This could include providing the remote veterinarian with the following information: i) a side-profile image of the cow to enable the remote veterinarian to assess characteristics associated with lameness such as arching on the back and improper stance; and (ii) a short (approximately 10 second) video clip of the cow while walking. This could enhance the ability of the remote veterinarian to assess locomotion score, the severity of the lesion, identify which limb is affected, and correctly identify body region and tissue affected and, may aid in overall diagnosis as the RV can assess the whole cow. It is anticipated

that improvement in agreement of all categories will ultimately improve the ability of the remote veterinarian to diagnose and provide an appropriate treatment protocol.

- Conduct a cost-analysis of the tele-foot-health system. Following this it may be possible to conduct a study using the Technology Acceptance Model (King & He 2006). The Technology Acceptance Model is a modification of the Theory of Panned Behaviour framework used in this thesis and provides a theoretical model to explain and predict user acceptance of and intentions to use a new technology. The Technology Acceptance Model suggests that perceived usefulness and perceived ease of use are the key components influencing an individual's decision to adopt a new technology or not.

## 6.3. Additional findings and recommendations

While a core objective of the systematic review was to determine which tests could be recommended for implementation on the dairy farm, this was not possible due to incomplete reporting of pertinent information and a high probability of risk of bias in the included studies. Therefore, an additional key finding of this thesis was evidence of poorly reported studies in the scientific literature. This is concerning as it suggests that much of the scientific literature may be non-replicable, an important tenet of scientific enquiry. This presents particular challenges for conducting systematic reviews as insufficient reporting of information precludes a thorough methodological quality assessment, leaving many components of the assessment to be considered as unclear. This results in unanswered research questions, as was the case for the systematic review presented in this thesis. While this is an undesirable outcome, the findings of systematic review are still considered important and demonstrate the need for greater rigour in the scientific literature.

Given this finding, the systematic review concluded with the following recommendations for authors of future studies in this field:

- When reporting research, it is essential to include the following: eligibility criteria and selection of animals, disease spectrum of selected animals, reference test operator and skill level, characteristics of dairy herds under investigation (e.g., DIM, feeding, housing and milking systems, parity and productivity), and sensitivity and specificity estimates.
- In the absence of a perfect reference test, alternative analytical methods, such as latent class analysis should be used.

- Follow and adhere to the STARD guidelines (Bossuyt et al. 2015) when planning and reporting research.

## 6.4. Key strengths and limitations

This thesis has a number of strengths. However, limitations are inherent in any scientific study. Each chapter included in this thesis demonstrates its own set of key strengths and limitations. These are discussed below for each chapter.

### 6.4.1. Chapter 3 - A systematic review of tests for the detection and diagnosis of foot lesions causing lameness in dairy cows

#### *Strengths*

First, the systematic review followed an explicit methodology, adhering to the guidelines and standards for conducting and reporting systematic reviews proposed by the Cochrane Collaboration. In line with these guidelines, a protocol was established *a priori* detailing the specific steps that would be taken to conduct the systematic review. This involved determining the specific objectives, target conditions, inclusion criteria for studies, search strategy for finding appropriate studies, what data would be extracted and how the quality of the studies would be assessed. Following these steps facilitates transparency, replicability and reduces the potential risk of bias. Second, while conducting the systematic review I received extensive mentorship from an individual with expertise in conducting and reporting systematic reviews. He closely monitored each step of the systematic review and provided guidance and support where necessary. Therefore, the systematic review has been conducted to a high standard and there is strong confidence in the conclusions drawn.

#### *Limitations*

First, while care was taken to create the most suitable search terms for each database used, all pertinent papers may not have been identified even if they were contained in the databases searched. Studies that were unpublished (i.e. abstracts), written in languages other than English, and those using a test based on mathematical modelling were excluded. Therefore, the systematic review does not include every possible study on this topic. Second, while I received extensive mentorship to conduct the systematic review, it was conducted primarily by myself. To ensure reliability, it is recommended that the systematic review process involves a minimum of two reviewers to carry out each step. Therefore, the reliability of the conclusions reached in this systematic review must be taken in this context.

### 6.4.2. Chapter 4 - Tele-medicine on the farm – a platform for improved farm worker diagnosis and treatment of foot lesions in dairy cows

*Strengths*

Studies assessing the level of agreement between two raters often only report proportion of overall agreement or Cohens kappa statistic and fail to provide 2 x 2 contingency tables. While these are important statistics for demonstrating inter-rater agreement, reported individually, these statistics can be misleading. This is because overall proportion of agreement fails to take the level of chance agreement into consideration and Cohens kappa statistic is influenced by bias between raters and the prevalence of the condition in the population; both of which can be observed in 2 x 2 contingency tables. Taking these caveats into consideration, this chapter has taken a holistic approach in the interpretation of inter-rater agreement by reporting a range of inter-rater agreement statistics rather than a single measure. For each category investigated, both proportion of overall agreement and Cohens kappa statistic were reported. In addition, supporting statistics, percent positive agreement, percent negative agreement, maximum kappa and prevalence and bias indices were reported, as well as 2 x 2 contingency tables. By reporting the aforementioned statistics, this chapter has provided full transparency of the extent of agreement between each set of raters. Therefore, these is strong confidence in the conclusions reached in this chapter.

*Limitations*

The data used in this study were not collected by myself. These data were acquired already extracted from the data collection forms used in the study, which were not available to access. Therefore, it was not possible to view the raw data and check for potential data entry errors or additional notes made by the raters. Second, the external validity of this study is limited to the skill levels and observations of the participating raters. Therefore, caution should be used in extrapolating the agreement results beyond this study. Third, this study was conducted using a single dairy herd and was therefore limited to the types of lesions occurring in this herd. Due to this, and the issue of prevalence of the various lesions, it was not possible to assess all possible lesion types. Thus, the reliability of the conclusions reached in this study must take this limitation into consideration.

### 6.4.3. Chapter 5 - Understanding dairy farmer intentions to make improvements to their management practices of foot lesions causing lameness in dairy cows

*Strengths*

First, Chapter 5 followed specific guidelines proposed for Theory of Planned Behaviour studies. This involved: conducting an elicitation study to identify the salient beliefs of the target population, phrasing statements for the questionnaire based on the principle of compatibility, and conducting a pilot study of the questionnaire and making changes as appropriate before distribution. Second, an individual with expertise in Theory of Planned Behaviour studies viewed the questionnaire prior to its distribution. Based on comments regarding some of the statements, the questionnaire was further amended. Therefore, there is strong confidence that the questionnaire adheres to the requirements of the Theory of Planned Behaviour framework.

*Limitations*

First, demographic data were not collected for the dairy farmers participating in the elicitation questionnaire, therefore it was not possible to determine if this sample was representative of the target population. This may have had follow-on implications for the questionnaire as the beliefs assessed may not have been the most appropriate for the wider population. In addition, because the questionnaire was limited to including only the three most salient beliefs for each construct, the potential to capture a wider range of beliefs in the questionnaire to address this issue was limited. Second, the study population for the questionnaire was biased towards younger dairy farmers who do not represent the target population. Therefore, the behavioural, normative and control beliefs demonstrating the stronger associations with intention may not represent the beliefs with the potential to have the greatest influence on dairy farmer intentions. Finally, there are limitations inherent in any questionnaire. These include issues with dishonesty, where individuals may choose the more positive responses to be viewed in positive light; lack of conscientious responses where individuals may not have considered the question thoroughly; and, potential difficulties understanding and interpreting the statements. This final issue has been demonstrated to be a problem for some statements in other Theory of Planned Behaviour studies. Thus, the reliability of the conclusions reached in this study must take these limitations into consideration.

## 6.5. Overall conclusion

This thesis has identified a number of important findings, contributing substantial new knowledge towards improving dairy farmer potential to identify foot lesions causing lameness in their dairy cows. It has demonstrated that dairy farmers need support in diagnosing foot lesions that affect the dairy cows in their herds. While no tools of this nature currently exist, the tele-foot-health system introduced in this thesis offers a potential solution to assist dairy farmers in both the diagnosis and treatment of foot lesions. To support the uptake of such tools, this thesis has identified the importance of targeting dairy farmer behavioural beliefs in the development of strategies to promote improved dairy cow foot health. This body of work provides direction for further research into tools to aid dairy farmers in improving their management of foot lesions causing lameness in their dairy herds.

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# 8. Appendices

## 8.1. Appendix 1: Systematic review protocol

### Review title

A systematic review of methods for the detection and diagnosis of foot lesions causing lameness in dairy cows.

### Primary reviewers/authors


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### Rationale

Foot lesions causing lameness in dairy cows are an important economic and welfare issue facing the dairy industry. The process of diagnosing a foot lesion, from initial detection through to final diagnosis, is an important task and often begins with observation of a lame cow. The literature suggests that dairy farmer detection of lameness is relatively poor (Wells et al. 1993; Leach et al. 2010; Šárová et al. 2011) , while there is little evidence available to determine dairy farmer ability to correctly diagnose the offending foot lesion/s. To aid the dairy farm worker in the detection and diagnosis of foot lesions, a number of methods have been investigated in the literature. As few have become commercially available, there is a need to assess the efficacy of these methods to make recommendation for those that show promise for implementation on the farm.

## Objective/s

The specific objective of this systematic review is to compare the sensitivity and specificity of methods, for the detection and diagnosis of lameness and foot lesions, in the context of study quality to determine which methods can be recommended for implementation on the farm.

## Methods

### *Inclusion criteria*

The following inclusion criteria will be applied to papers:

- Peer-reviewed papers written in English
- A description of a method used for the detection of lameness or the detection or diagnosis of foot lesions in dairy cows is provided
- A reference test is used
- Primiparous and/or multiparous lactating dairy cows are used
- Sensitivity and specificity data are provided

### *Types of studies*

All prospective observational studies will be eligible for inclusion.

### *Animals*

Studies that include primiparous and/or multiparous lactating dairy cows will be included. Studies including heifers will be excluded because lesions primarily affect dairy cows approaching parturition or at parity one or greater.

### *Index tests*

All available methods (technologies and observations) used for detection and diagnosis of lameness and of foot lesions will be considered.

### *Target condition*

Foot lesions causing lameness, where the term "foot lesion" includes all lesions of the cow foot and hoof. For the purpose of this systematic review, studies with the objective of detecting lameness will also be included as the clinical presentation of lameness is typically the first indication of the presence of a foot lesion.

### *Search methods for identification of studies*

#### Information sources

The search engines that will be used to identify appropriate papers are: i) PubMed, using medical subject headings (MeSH) (1951 - February 2015), ii) Web of Science, Core Collection, advanced search (1990 – February 2015), and iii) Agricola, advanced search (1970 - February 2015). The reference lists of eligible papers will be checked for additional relevant papers.

#### Search strategy

Database specific search terms will be created with the assistance of a librarian at The University of Queensland to ensure the database search contains literature relevant to the topic.

### Data collection process

#### *Data management*

Identified eligible studies will be imported into Endnote™ (Thomson Reuters, Endnote X7.2). The required relevant information and data will be extracted and entered in an Excel® spreadsheet for analysis.

#### *Selection process*

The primary reviewer (KDR) will independently and primarily review abstracts to retrieve potentially relevant studies. Full text of records that appear to meet the inclusion criteria will be retrieved and then subjected to a second phase of screening for eligibility by the primary reviewer. We will seek additional information from study authors where necessary to resolve questions about eligibility. Any hesitation in the decision of an articles eligibility will be discussed with the second reviewer (AR). Reasons for ineligibility will be documented for all excluded studies. A PRISMA flow chart will be provided to outline the study selection process and reasons for exclusions.

#### *Data extraction*

A standardized form will be developed, adapted from the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) statement checklist of items that should be included in reports of observational studies, to target the objectives of the review. The form will be pilot tested using a representative sample of the studies to be reviewed and amended if necessary. The following information will be extracted from studies: author and publication date, publication type (e.g. journal article, short communication), setting and methods (e.g. country, context, study design), population (e.g. eligibility/selection criteria, number of cows, health status of included cows, number of farms, withdrawals, mean parity, average days in milk (DIM), daily or yearly milk yield, feed type, housing and milking system), details of the method investigated (e.g., manufacturer, operator, settings), type of test (e.g., screening, monitoring), details of reference test (e.g. operator, settings, definition of positive case), unit of analysis (e.g. cow, hind limb), measures of test accuracy (i.e. sensitivity and specificity), data for two-by-two tables (TP, TN, FP, FN), prevalence, and main conclusions. Where there were missing data, the corresponding author/s were contacted to obtain further information.

This information will be extracted for all studies by one reviewer (KDR), after which the extracted data will be verified by a second reviewer (AR) to verify the accuracy of data collection and reduce the potential sources of bias.

### Assessment of methodological quality

To assess the methodological quality for each study, full copies of the studies will be independently assessed by the two reviewers (KDR & AR) using signalling questions of the QUADAS-2 tool for risk of bias and concerns of applicability. The following domains will be assessed: (i) animal selection, (ii) index test, (iii) reference test, and (iv) flow and timing. All domains will be assessed for risk of bias. In addition the first three will also be assessed for concerns of applicability. Judgement will be made from the extracted information and rated as ‘high risk’, ‘low risk’ or ‘unclear’. If there is insufficient detail reported in the study, the author will be contacted for further clarification.

### Data analysis

Sensitivity and Sp values will be interpreted in the context of methodological quality to compare the technologies identified.

## 8.2. Appendix 2: Search strategies used for each data-bases used for the literature search.

Table 8-1: Search strategy used for the data-base PubMed.

| **Database: PubMed** | **Database-tailored syntax (using Boolean operators)** |
|---|---|
| **Term** | |
| **1** | "Cattle"[Mesh] |
| | **AND** |
| **2** | "Lameness, Animal"[Mesh] OR "Locomotion"[Mesh:NoExp] OR "Foot Diseases/veterinary"[Mesh:NoExp] OR "Hoof and Claw"[Mesh] OR "Gait"[Mesh] OR "Osteoarthritis/veterinary"[Mesh] OR "Digital Dermatitis"[Mesh] |
| | **AND** |
| **3** | "Diagnosis"[Mesh] OR "Investigative Techniques"[Mesh] OR "Signal Processing, Computer-Assisted"[Mesh] OR "Infrared Rays"[Mesh] OR "Video Recording"[Mesh] OR "Technology/veterinary"[Mesh] OR "diagnosis" [Subheading:NoExp] OR "radiography" [Subheading] OR "radionuclide imaging" [Subheading] OR "ultrasonography" [Subheading] |

Table 8-2: Search strategy used for the data-base Web of Science.

| **Database: Web of Science (WOS)** | **Database-tailored syntax (using Boolean operators)** |
|---|---|
| **Term** | |
| 1 | TS=(cows OR cattle OR bovine OR dairy-cow) |
| | **AND** |
| 2 | TS=(lameness OR gait OR locomot* OR lesions OR "hoof pathologies" OR "sole ulcers" OR laminitis) |
| | **AND** |
| 3 | TS=(diagnos* OR detect* OR pedomet* OR scor* OR thermograph* OR system OR ultrasound OR image OR lying OR sensor*) |

Table 8-3: Search strategy used for the data-base Agricola.

| **Database: Agricola** | **Database-tailored syntax (using Boolean operators)** |
|---|---|
| **Term** | |
| 1 | dairy cattle lameness |
| | **AND** |
| 2 & 3 | diagnos? assess? analys? technolog? |

## 8.3. Appendix 3: Data extraction form

# Item Information

| | |
|---|---|
| Review title or ID | |
| Study ID *(surname of first author and year first published)* | |
| Notes | |

# General Information

| | |
|---|---|
| Date form completed | |
| Name/ID of person extracting data | |
| Reference citation | |
| Study author contact details | |
| Publication type | |
| Notes: | |

# Study Eligibility

| Study Characteristics | Eligibility criteria | Eligibility criteria met? Yes | No | Unclear | Location in text or source |
|---|---|---|---|---|---|
| Source | Journal Article, short communication | ☐ | ☐ | ☐ | |
| Language | English | ☐ | ☐ | ☐ | |
| Participants | Lactating dairy cows | ☐ | ☐ | ☐ | |
| Sample size | Number of herds and number of cows in study specified | ☐ | ☐ | ☐ | |
| Type of test | Test described adequately | ☐ | ☐ | ☐ | |
| Reference test | Test described adequately | ☐ | ☐ | ☐ | |
| Study design | Described in detail | ☐ | ☐ | ☐ | |
| Types of outcome measures | Sensitivity (Se) and Specificity (Sp) | ☐ | ☐ | ☐ | |
| INCLUDE ☐ | | | EXCLUDE ☐ | | |

| | |
|---|---|
| Reason for exclusion | |
| Notes: | |

***DO NOT PROCEED IF STUDY EXCLUDED FROM REVIEW**

# Characteristics of included studies

## Methods

| | **Descriptions as stated in report/paper** | **Location in text or source** |
|---|---|---|
| Aim of study | | |
| Methodology description | | |
| Lameness or hoof lesion definition used in study | | |
| Unit of observation | | |
| Unit of analysis | | |
| Study dates | | |
| Ethical approval needed/ obtained for study | ☐ Yes ☐ No ☐ Unclear | |
| Notes: | | |

### Participants

| | Description | Location in text or source |
|---|---|---|
| Population description *(breed, how many, parity number etc.)* | | |
| Setting *(location)* | | |
| Housing type | | |
| Feed | | |
| Milking system | | |
| Inclusion criteria | | |
| Exclusion criteria | | |
| Method of recruitment of participants | | |

| | | |
|---|---|---|
| Withdrawals and exclusions | | |
| Other relevant information | | |
| Notes: | | |

## Index Test

| | Description as stated in report/paper | Location in text or source |
|---|---|---|
| Test Description | | |
| Test type *(Screening, diagnosis, monitoring, etc.)* | | |
| Test manufacturer | | |
| Timing *(e.g. frequency, duration of each episode)* | | |
| Operator/s | | |
| Skill level of operator/s | | |
| Concordance between raters | | |
| Notes: | | |

## Reference standard

| | Description as stated in report/paper | Location in text or source |
|---|---|---|
| Description | | |
| Operator/s | | |
| Skill level of operator/s | | |
| Concordance between operators | | |
| Notes | | |

## Outcomes

| | Description as stated in report/paper | Location in text or source |
|---|---|---|
| Se & Se | | |
| TP, TN, FP, FN | | |
| Prevalence | | |

| | | |
|---|---|---|
| Any other results reported | | |
| Number of excluded animals and justification | | |
| Notes | | |

## Other Information

| | **Description as stated in report/paper** | **Location in text or source** |
|---|---|---|
| Key conclusions of study authors | | |
| References to other relevant studies | | |
| Correspondence required for further study information | | |
| Notes: | | |

## 8.4. Appendix 4: Scoring guidance for signalling questions of each domain of the QUADAS-2 tool

### Risk of bias

1. **Animal selection**

**a. Was a random sample of animals used in the study?**

- Yes: when the authors report random animal sampling.
- No: When animals were not selected randomly.
- Unclear: When selection of animals is not specified

**b. Was the spectrum of animals used representative of the population that will receive the test in a farm setting?**

- Yes: When animals were selected across a range of characteristics, i.e.: inclusion of all levels of disease status: not lame, mild lameness or severely lame; inclusion of a range of cows at various parity number
- No: When limited subgroups of animals were selected, i.e. only severely lame cows or only parity one cows
- Unclear: When the composition of animals used is not reported

**c. Did the study avoid inappropriate exclusions?**

- Yes: When no animals were purposely excluded
- No: When, for example, animals with low disease status were excluded because they are more difficult to detect.
- Unclear: Insufficient information is reported to permit a decision.

2. **Index test**

**a. Were the index test results interpreted without knowledge of the results of the reference standard?**

- Yes: when results of the index tests are interpreted without knowledge of reference test results, for example, when the index test is conducted before the reference standard; different observers perform each test; or the study authors report blinding.

- No: when results of the index tests are interpreted with knowledge of reference test results, for example when the reference test is conducted before the index test or the tests are conducted by the same operator.
- Unclear: when information regarding when and by who the index and reference tests were interpreted is insufficient.

**b. If a threshold was used, was it pre-specified?**

- Yes: when the study authors report the use of a pre-specified cut-off value in the methodology. A pre-specified threshold also includes statements such as, “the test was scored according to manufacturer’s instructions.”
- No: when multiple cut-off values were tested and the best one chosen afterwards.
- Unclear: when a cut-off value was used but this was not explicitly stated in the methodology.
- NA: The index test did not require a threshold

**c. Had test operators had appropriate training/experience?**

- Yes: When the study authors report the level of training or experience of the operator/s specific to the index test.
- No: When training or experience reported is inadequate or not relevant to the index test used.
- Unclear: When the level of training of the operator/s is not reported.
- NA: if the test did not require an operator

**d. Were data on observer variation reported and within an acceptable range?**

- Yes: When the study authors report inter-rater agreement between two or more observers. Agreement is reported as good or higher.
- No: When inter-rater agreement between two or more observers is not reported or reported but reported as poor.
- Unclear: Where there is insufficient information reported
- NA: When only one observer performed the test

3. **Reference test**

**a. Is the reference standard likely to correctly classify the target condition?**

- Yes: if appropriate measures to increase sensitivity are used, i.e. detailed definition of a positive case; qualified operator.
- No: if no measures to increase sensitivity are used, i.e. no definition of a positive case is provided; operator is not qualified. Where a subjective reference test is used, this is considered to be a potential source of bias.
- Unclear: information on the reference standard used is insufficient, i.e.: definition of positive case is insufficient; qualifications of operator are unclear.

**b. Were the reference standard results interpreted without knowledge of results of the index test?**

- Yes: when results of the reference tests are interpreted without knowledge of index test, for example when the reference standard is used before the index test; different observers perform each test; or the study authors report blinding.
- No: when results of the reference test are interpreted with knowledge of the index, for example when index tests are used before reference tests or the tests are conducted by the same operator.
- Unclear: when information on when and by who the index and reference tests were interpreted is insufficient

**c. Did animals receive the same reference standard irrespective of the index test result?**

- Yes: all animals received the same reference standard
- No: all animals did not receive the same reference standard
- Unclear: Where there is insufficient information reported to permit a judgement

**d. Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)?**

- Yes: the index test did not form part of the reference standard.
- No: the index test did form part of the reference standard
- Unclear: Where there is insufficient information reported to permit a judgement

**e. Did the study provide a clear definition of what was considered to be a positive result?**

- Yes: a clear definition of the condition was provided
- No: a clear definition of condition was not provided
- Unclear: Where the definition was insufficient

**f. Had test operators had appropriate training/experience?**

- Yes: When the study authors report the level of training or experience of the operator/s relevant to the reference test.
- No: When training or experience reported is inadequate or not relevant to the reference test used.
- Unclear: When the level of training of the operator/s is not reported or insufficient information is reported to judge training/experience as adequate.

**g. Were data on observer variation reported and within an acceptable range?**

- Yes: When the study authors report inter-rater agreement between two or more observers. Agreement is reported as good.
- No: When inter-rater agreement between two or more observers is not reported or reported but reported as poor.
- Unclear: Where there is insufficient information reported
- NA: When only one observer performed the test.

**4. Flow and timing**

**a. Was there an appropriate interval between index test(s) and reference standard?**

- Yes: if both the reference standard and the index standard were performed at the same time, or if the time period is less than 24 hours.
- No: if time period between index and reference standards is longer than 24 hours.
- Unclear: if no or insufficient information on time period is provided.

**b. Did all animals receive the same reference standard?**

- Yes: where all study participants are tested with the same reference standard.

- No: where one or more study participants are tested with a different reference standard to other animals.
- Unclear: when no or insufficient information is provided to permit a judgement

**c. Were withdrawn animals explained?**

- Yes: when justification was provided for animals removed from analysis.
- No: if there are participants missing or excluded from the analysis and there is no explanation given.
- Unclear: when insufficient information is provided to permit a judgement
- NA: When there were clearly no animals reported as withdrawn.

**d. Was treatment withheld until both the index test and reference standard were performed?**

- Yes: When any treatment reported was applied after both index and reference tests were performed
- No: When any treatment reported was applied prior to either index or reference tests
- Unclear: when no or insufficient information is provided to permit a judgement

## 8.5. Appendix 5: Characteristics of excluded studies

Table 8-4: Characteristics of excluded studies.

| Author (year) | Study title | Reason for exclusion | Index test | Type of lesion |
|---|---|---|---|---|
| Alsaaod et al. (2012) | Electronic detection of lameness in dairy cows through measuring pedometric activity and lying behaviour | No Se/Sp data reported | Mathematical model | Lameness |
| Berry et al. (2008) | Locomotion scoring of cattle using a lameness-speed index on different types of track | No Se/Sp data reported | Gait scoring system | Lameness |
| Borderas et al. (2007) | Effect of lameness on dairy cows' visits to automatic milking systems | No Se/Sp data reported | Mathematical model | Lameness |
| Brenninkmeyer et al. (2007) | Reliability of a subjective lameness scoring system for dairy cows | No Se/Sp data reported | Gait scoring system | Lameness |
| Channon et al. (2009) | Variability of Manson and Leaver locomotion scores assigned to cows by different observers | No Se/Sp data reported | Gait scoring system | Lameness |
| Chapinal and Tucker (2012) | validation of an automated method to count steps while cows stand on a weighing platform and its application as a measure to detect lameness | No Se/Sp data reported | Mathematical model | Lameness |
| Chapinal et al. (2009) | Using gait score, walking speed, and lying behaviour to detect lameness in dairy cows | No Se/Sp data reported | Gait scoring system | Lameness |
| Chapinal et al. (2010b) | Automated methods for detecting lameness and measuring analgesia in dairy cows | No Se/Sp data reported | Mathematical model | Lameness |
| Chapinal et al. (2010a) | Correlated changes in behavioural indicators of lameness in dairy cows following hoof trimming | No Se/Sp data reported | Gait scoring system, weighing platform & walking speed | Lameness |
| Chapinal et al. (2011) | Measurement of acceleration while walking as an automated method for gait assessment in dairy cattle | No Se/Sp data reported | 3D Accelerometer | Lameness |

| Author (year) | Study title | Reason for exclusion | Index test | Type of lesion |
|---|---|---|---|---|
| Engel et al. (2003) | Assessment of observer performance in a subjective scoring system: visual classification of the gait of cows | No Se/Sp data reported | Gait scoring system | Lameness |
| Flower and Weary (2006) | Effect of Hoof Pathologies on Subjective assessments of dairy cow gait | No Se/Sp data reported | Gait scoring system | Lameness |
| Gonzalez et al. (2008) | Changes in Feeding Behaviour as Possible Indicators for the Automatic Monitoring of Health disorders in dairy cows | No Se/Sp data reported | Mathematical model | Lameness |
| Heppelmann et al. (2009) | Ultrasonographic diagnosis of septic arthritis of the distal interphalangeal joint in cattle | Unclear if milking cows | Ultrasonography | Septic arthritis |
| Ito et al. (2010) | Lying behaviour as an indicator of lameness in dairy cows | No Se/Sp data reported | Accelerometer | Lameness |
| Kujala et al. (2008) | Use of force sensors to detect and analyse lameness in dairy cows | No Se/Sp data reported | Weighing platform | Lameness |
| March et al. (2007) | Effect of training on the inter-observer reliability of lameness scoring in dairy cattle | No Se/Sp data reported | Gait scoring system | Lameness |
| MacCallum et al. (2002) | A field investigation of the use of the pedometer for the early detection of lameness in cattle | No Se/Sp data reported | Pedometer | Lameness |
| Nikkhah et al. (2005) | *Short Communication:* Infrared Thermography and Visual Examination of Hooves of Dairy Cows in Two Stages of Lactation | No Se/Sp data reported | Infra-red thermography | Laminitis |
| Pastell and Madsen (2008) | Application of CUSUM charts to detect lameness in a milking robot | No Se/Sp data reported | CUSUM Charts | Lameness |
| Pastell et al. (2006) | Assessing Cows' Welfare: weighing the Cow in a Milking Robot | No Se/Sp data reported | Balance system | Lameness |
| Pastell and Kujala (2007) | Arthosonography- the use of diagnostic | No Se/Sp data reported | Load sensors | Lameness |

| Author (year) | Study title | Reason for exclusion | Index test | Type of lesion |
|---|---|---|---|---|
| | ultrasound in septic and traumatic arthritis in cattle – a retrospective study of 25 patients | | | |
| Pastell et al. (2008) | Detecting cow's lameness using force sensors | No Se/Sp data reported | Balance system | Lameness |
| Pastell et al. (2009) | A wireless accelerometer system with wavelet analysis for assessing lameness in dairy cows | No Se/Sp data reported | Mathematical model | Lameness |
| Pastell et al. (2010) | Measures of weight distribution of dairy cows to detect lameness and the presence of hoof lesions | No Se/Sp data reported | Weighing platform | Lameness |
| Pluk et al. (2012) | Automatic measurement of touch and release angles of the fetlock joint for lameness detection in dairy cattle using vision technique | No Se/Sp data reported | Mathematical model | Lameness |
| Poursaberi et al. (2010) | Real time automatic lameness detection based on back posture extraction in dairy cattle: shape analysis of cow with image processing techniques | No Se/Sp data reported | Computer image analysis techniques | Lameness |
| Rajkondawar et al. (2006) | Comparison of Models to Identify Lame Cows Based on Gait and Lesion Scores, and Limb Movement Variables | No Se/Sp data reported | Mathematical model | Lameness |
| Rushen et al. (2007) | Validation of two measures of lameness in dairy cows | No Se/Sp data reported | Weighing platform | Lameness |
| Schlageter-Tello et al. (2014) | Effect of merging levels of locomotion scores for dairy cows on intra- and interrater reliability and agreement | No Se/Sp data reported | Gait scoring system | Lameness |
| Song et al. (2008) | Automatic detection of lameness in dairy cattle - vision based trackway analysis in cows locomotion | No Se/Sp data reported | Computer image analysis techniques | Lameness |
| Sprecher et al. (1997) | A lameness scoring system that uses posture and gait to predict dairy | No Se/Sp data reported | Gait scoring system | Lameness |

| Author (year) | Study title | Reason for exclusion | Index test | Type of lesion |
|---|---|---|---|---|
| | cattle reproductive performance | | | |
| Tanida et al. (2011) | Use of three-dimensional acceleration sensing to assess dairy cow gait and the effects of hoof trimmingasj_9 | No Se/Sp data reported | 3D Accelerometer | Lameness |
| Tasch and Rajkondawar (2004) | The development of a SoftSeparatorTM for a lameness diagnostic system | No Se/Sp data reported | Mathematical model | Lameness |
| Thomsen and Baadsgaard (2006) | Intra- and inter-observer agreement of a protocol for clinical examination of dairy cows | No Se/Sp data reported | Gait scoring system | Lameness |
| Thomsen et al. (2008b) | Evaluation of a Lameness Scoring System for Dairy Cow | No Se/Sp data reported | Gait scoring system | Lameness |
| Thomsen et al. (2012) | Locomotion scores and lying behaviour are indicators of hoof lesions in dairy cows | No Se/Sp data reported | Accelerometer | Hoof lesions |
| Thorup et al. (2014) | Short communication: Changes in gait symmetry in healthy and lame dairy cows based on 3-dimensional ground reaction force curves following claw trimming | No Se/Sp data reported | Force plates | Lameness |
| Viazzi et al. (2013) | Analysis of individual classification of lameness using automatic measurement of back posture in dairy cattle | No Se/Sp data reported | Mathematical model | Lameness |
| Winckler and Willen (2001a) | The reliability and repeatability of a lameness scoring system for use as an indicator of welfare in dairy cattle | No Se/Sp data reported | Gait scoring system | Lameness |
| Wood et al. (2015) | Infrared thermometry for lesion monitoring in cattle lameness | No Se/Sp data reported | Infra-red thermography | Hoof lesions |

## 8.6. Appendix 6: Characteristics of excluded studies - mathematical modelling papers

Table 8-5: Characteristics of excluded studies – mathematical modelling papers.

| Author (year) | Study title | Mathematical model | Index test | Type of lesion |
|---|---|---|---|---|
| de Mol et al. (2013) | Applicability of day-to-day variation in behaviour for the automated detection of lameness in dairy cows. | Dynamic linear model | 3-D accelerometer, automated milking system & concentrate feeders | Lameness |
| Garcia et al. (2014) | Lameness detection challenges in automated milking systems addressed with partial least squares discriminant analysis | Partial least squares discriminant analysis | Activity tag, automated milking system | Lameness |
| Kamphuis et al. (2013) | Applying additive logistic regression to data derived from sensors monitoring behavioural and physiological characteristics of dairy cows to detect lameness | Additive logistic regression (applying LogitBoost algorithm) | Weight scales, pedometer, milk meters | Lameness |
| Kramer et al. (2009) | Mastitis and lameness detection in dairy cows by application of fuzzy logic | Fuzzy logic model | Milk meter, feeding trough, neck transponder | Lameness |
| Liu et al. (2009) | Enhancing the prediction accuracy of bovine lameness models through transformations of limb movement variables | Logistic regression model (with B-spline LMV transformation) | Sensor platform | Lameness |
| Machado et al. (2011) | Use of data collected at cessation of lactation to predict incidence of sole ulcers and white line disease during the subsequent lactation in dairy cow | Logistic regression model | Visual observation, Ultrasonography, history taking | Prediction of claw horn disruption |
| Maertens et al. (2011) | Development of a rea time cow gait tracking and analysing tool to assess lameness using a pressure sensitive walkway: The GAITWISE system | Linear regression model | Force plate /pressure system | Lameness |
| Miekley et al. (2013b) | Principal component analysis for the early detection of mastitis and lameness in dairy cows | Principal component analysis | Pedometer and feeding trough | Lameness |

| Author (year) | Study title | Mathematical model | Index test | Type of lesion |
|---|---|---|---|---|
| Miekley et al. (2013a) | Implementation of multivariate cumulative sum control charts in mastitis and lameness monitoring | Multivariate cumulative sum (MCUSUM) charts (classic) using multivariate vector autoregressive (VAR) models | Pedometer and feeding trough | Lameness |
| Ghotoorlar et al. (2012) | Lameness scoring system for dairy cows using force plates and artificial intelligence | Artificial neural network system | Four-force plate balance system | Lameness |
| Pastell and Kujala (2007) | A probabilistic neural network model for lameness detection | Probalistic Neural Network model | 4-balance system | Lameness |
| Van Hertem et al. (2013) | Lameness detection based on multivariate continuous sensing of milk yield, rumination, and neck activity | Logistic regression model | Neck collar tag and milk yield metre | Lameness |
| Van Hertem et al. (2014) | Automatic lameness detection based on consecutive 3D video recordings | Linear regression | 3D camera | Lameness |
| Viazzi et al. (2014) | Comparison of a three-dimensional and two-dimensional camera system for automated measurement of back posture in dairy cows | Decision tree classifier (Computer vision based algorithm) | 3D camera | Lameness |

## 8.7. Appendix 7: Details of each index test including manufacturer details and a description of the index test

Table 8-6: Details of each index test including manufacturer details and a description of the index test.

| Author | Index test | Manufacturer | Description of index test |
|---|---|---|---|
| **Lameness detection** | | | |
| Leach et al. (2009) | Observation of lameness indicators | NA | Visual observation of a cow standing in a tie-stall, assessing for the presence of lameness indicators |
| Thomsen (2009) | Observation of arched back | NA | Visual observation of a cow standing in a free-stall, assessing for the presence of an arched back. |
| **Foot lesion detection** | | | |
| Alsaaod and Buscher (2012) | Infra-red thermography | Jenoptik varioCAM high resolution, long wave thermal camera, 7.5 - 14µm: series model - 'research', with 60 individual frames/recording. | Equipment that detects infrared energy emitted from an object and converts it to a temperature reading |
| Bicalho et al. (2007a) Study 1 | Locomotion scoring system | NA | A scoring system for identifying lame cows, based on observations made while the cow is walking (cow gait). Scale (1-5) where: 1 = normal, 2= presence slightly asymmetrical gait, 3=cow clearly favours one or more limbs, 4= severely lame, 5= extremely lame |
| Bicalho et al. (2007a) Study 2 | Force plate system | StepMetrix™ | A sensor platform that analyses the force and duration of each step. |
| Main et al. (2012) | Infra-red thermography | Product code N85FR, Maplin Electronics | Equipment that detects infrared energy emitted from an object and converts it to a temperature reading |
| Stokes et al. (2012a) | Infra-red thermography | ThermaCAM E2, FLIR Systems | Equipment that detects infrared energy emitted from an object and converts it to a temperature reading |
| **Sole ulcer detection** | | | |
| Chapinal et al. (2009) Study 1 | Observation of abduction/adduction | NA | A cow demonstrating abduction/adduction while walking |
| Chapinal et al. (2009) Study 2 | Observation of back arch | NA | A cow demonstrating an arched back while standing |
| Chapinal et al. (2009) Study 3 | Observation of head bob | NA | A cow demonstrating head bob while walking |
| Chapinal et al. (2009) Study 4 | Observation of tracking up | NA | A cow demonstrating tracking up |
| Chapinal et al. (2009) Study 5 | Observation of joint flexion | NA | A cow demonstrating joint flexion |
| Chapinal et al. (2009) Study 6 | Observation of asymmetric gait | NA | A cow demonstrating asymmetric steps |

| Author | Index test | Manufacturer | Description of index test |
|---|---|---|---|
| Chapinal et al. (2009) Study 7 | Observation of reluctance to bear weight | NA | A cow demonstrating reluctance to bear weight on the affected limb/s |
| **Digital dermatitis detection** | | | |
| Alsaaod et al. (2014) | Infrared thermography | Ti25 Thermal Imager (Fluke IR- Fusion technology | Equipment that detects infrared energy emitted from an object and converts it to a temperature reading. |
| Relun et al. (2011) | Visual inspection in milking parlour with swivelling mirror and headlamp | Telescopic swiveling inspection mirror: 1PK390G Prokit's Industries Co. Ltd.,Hsin Tien, Taiwan Headlamp: Petzl Tikka Plus; Petzl, Crolles France | Visual observation of a cow standing in the milking parlour, assessing for the presence of digital dermatitis using a swivelling mirror |
| Rodriguez-Lainz et al. (1998) | Visual inspection in milking parlour | NA | Visual observation of a cow standing in the milking parlour, assessing for the presence of digital dermatitis |
| Stokes et al. (2012b) Study 1 | Visual inspection in milking parlour | NA | Visual observation of a cow standing in the milking parlour, assessing for the presence of digital dermatitis |
| Stokes et al. (2012b) Study 2 | Visual inspection in milking parlour using a borescope | Not reported | Visual observation of a cow standing in the milking parlour, assessing for the presence of digital dermatitis using a borescope (an optical device consisting of a rigid or flexible tube with an eyepiece on one end, and an objective lens on the other linked together by a relay optical system in between). |
| Thomsen et al. (2008a) | Visual inspection in milking parlour | NA | Visual observation of a cow standing in the milking parlour, assessing for the presence of digital dermatitis |

## 8.8. Appendix 8: Review authors' judgements for each signalling question of each domain for each included study

**Lameness detection**

| Author, year: (Leach et al. 2009)<br>Index test: Observation of lameness indicators | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Unclear | Unclear |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | NA | NA |
| c) Had test operators had appropriate training/experience? | Yes | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Yes | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | NA | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Unclear | |

| Author, year: (Thomsen 2009)<br>Index test: Observation of arched back | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Unclear | Unclear |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Yes | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | No | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | NA |
| b) Did all animals receive the same reference standard? | Yes | NA |
| c) Were withdrawn animals explained | NA | NA |
| d) Was treatment withheld until both the index test and reference standard were performed? | Unclear | NA |

**Foot lesion detection**

| Author, year: (Alsaaod & Buscher 2012)<br>Index test: Infra-red thermography | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | No[1] | High |
| c) Did the study avoid inappropriate exclusions | No[1] | High |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | No | Low |
| c) Had test operators had appropriate training/experience? | NA | NA |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Unclear | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | NA |
| b) Did all animals receive the same reference standard? | Yes | NA |
| c) Were withdrawn animals explained | NA | NA |
| d) Was treatment withheld until both the index test and reference standard were performed? | No | NA |

[1] Only first and second parity cows were enrolled in the study

| Author, year: (Bicalho et al. 2007a) Study 1<br>Index test: Force plate system | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Unclear | Unclear |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | NA | NA |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Unclear | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | Low |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | NA |
| b) Did all animals receive the same reference standard? | Yes | NA |
| c) Were withdrawn animals explained | No | NA |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | NA |

| Author, year: (Bicalho et al. 2007a) Study 2<br>Index test: Locomotion scoring system | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Unclear | Unclear |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Yes | Low |
| d) Were data on observer variation reported and within an acceptable range? | Yes | Low |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | No | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Unclear | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | Low |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | Yes | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

| Author, year: (Main et al. 2012)<br>Index test: Infra-red thermography | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Unclear | Unclear |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | No | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | No | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Unclear | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | NA | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

| Author, year: (Stokes et al. 2012a)<br>Index test: Infra-red thermography | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear[1] | High |
| c) Did the study avoid inappropriate exclusions | Unclear[1] | High |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | No | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | Unclear[2] | Low |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | No | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Unclear | Low |
| g) Were data on observer variation reported and within an acceptable range? | Unclear[2] | Low |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | NA | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1] It is not clear if a wide spectrum of cows with digital dermatitis were included in the study, [2] the number of operators is not reported; therefore, it is unknown whether data on concordance is required.

**Sole ulcer detection**

| Author, year: (Chapinal et al. 2009) Study 1<br>Index test: Observation of gait characteristic abduction/adduction | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | No[1] | High |
| c) Did the study avoid inappropriate exclusions | No[1] | High |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | Yes | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1]primiparous cows were removed because they consistently had lower locomotion scores than multiparous cows

| Author, year: (Chapinal et al. 2009) Study 2<br>Index test: Observation of gait characteristic back arch | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | No[1] | High |
| c) Did the study avoid inappropriate exclusions | No[1] | High |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | Yes | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1]primiparous cows were removed because they consistently had lower locomotion scores than multiparous cows

| Author, year: (Chapinal et al. 2009) Study 3<br>Index test: Observation of gait characteristic head bob | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | No[1] | High |
| c) Did the study avoid inappropriate exclusions | No[1] | High |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | Yes | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1]primiparous cows were removed because they consistently had lower locomotion scores than multiparous cows

| Author, year: (Chapinal et al. 2009) Study 4<br>Index test: Observation of gait characteristic tracking up | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | No[1] | High |
| c) Did the study avoid inappropriate exclusions | No[1] | High |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | Yes | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1]primiparous cows were removed because they consistently had lower locomotion scores than multiparous cows

| Author, year: (Chapinal et al. 2009) Study 5<br>Index test: Observation of gait characteristic joint flexion | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | No[1] | High |
| c) Did the study avoid inappropriate exclusions | No[1] | High |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | Yes | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1]primiparous cows were removed because they consistently had lower locomotion scores than multiparous cows

| Author, year: (Chapinal et al. 2009) Study 6<br>Index test: Observation of gait characteristic asymmetric gait | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | No[1] | High |
| c) Did the study avoid inappropriate exclusions | No[1] | High |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | Yes | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1]primiparous cows were removed because they consistently had lower locomotion scores than multiparous cows

| Author, year: (Chapinal et al. 2009) Study 7<br>Index test: Observation of gait characteristic reluctance to bear weight | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | No[1] | High |
| c) Did the study avoid inappropriate exclusions | No[1] | High |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | Yes | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1]primiparous cows were removed because they consistently had lower locomotion scores than multiparous cows

**Digital dermatitis detection**

| Author, year: (Alsaaod et al. 2014)<br>Infra-red thermography | Risk of bias | Concerns of applicability |
|---|---|---|
| Alsaaod 2014 | | |
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Unclear | Unclear |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | No | Low |
| c) Had test operators had appropriate training/experience? | NA | NA |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Unclear | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | No[1] | Low |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | NA |
| b) Did all animals receive the same reference standard? | Yes | NA |
| c) Were withdrawn animals explained | Yes | NA |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | NA |

[1] Concordance was not reported for the two observers

| **Author, year:** (Relun et al. 2011)<br>Index test: Visual inspection in milk parlour with swivelling mirror and powerful headlamp | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Unclear | Unclear |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Yes | Low |
| d) Were data on observer variation reported and within an acceptable range? | Yes | Low |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | No | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | No[1] | Low |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | NA | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Unclear | |

[1]Concordance was not reported for the observers

| Author, year: (Rodriguez-Lainz et al. 1998)<br>Index test: Visual inspection in milking parlour | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Unclear | Unclear |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | Unclear[1] | Low |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Yes | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Unclear | Low |
| g) Were data on observer variation reported and within an acceptable range? | Unclear* | Low |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | No | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | Yes | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1] The number of operators is not reported; therefore, it is unknown whether data on concordance is required

| Author, year: (Stokes et al. 2012b) Study 1<br>Index test: Inspection with borescope | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear[1] | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear[1] | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | NA | Low |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | Unclear[2] | Low |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | No | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Unclear | Low |
| g) Were data on observer variation reported and within an acceptable range? | Unclear[2] | Low |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | NA | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1] It is not clear if a wide spectrum of cows with digital dermatitis were included in the study, [2] the number of operators is not reported; therefore, it is unknown whether data on concordance is required.

| Author, year: (Stokes et al. 2012b) Study 2<br>Index test: Visual inspection in milking parlour | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Yes | Low |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear[1] | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear[1] | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | NA | NA |
| c) Had test operators had appropriate training/experience? | Unclear | Low |
| d) Were data on observer variation reported and within an acceptable range? | Unclear[2] | Low |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | No | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Unclear | Low |
| g) Were data on observer variation reported and within an acceptable range? | Unclear[2] | Low |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | NA | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Yes | |

[1] It is not clear if a wide spectrum of cows with digital dermatitis were included in the study, [2] the number of operators is not reported; therefore, it is unknown whether data on concordance is required.

| Author, year: (Thomsen et al. 2008a)<br>Index test: Visual inspection in milk parlour | Risk of bias | Concerns of applicability |
|---|---|---|
| **Domain 1: Animal selection** | | |
| a) Was a random sample of animals used in the study? | Unclear | Unclear |
| b) Was the spectrum of animals used representative of the population that will receive the test in a farm setting? | Unclear | Unclear |
| c) Did the study avoid inappropriate exclusions | Unclear | Unclear |
| | | |
| **Domain 2: Index test** | | |
| a) Were the index test results interpreted without knowledge of the results of the reference standard? | Yes | Low |
| b) If a threshold was used was it pre-specified? | Yes | Low |
| c) Had test operators had appropriate training/experience? | Yes | Low |
| d) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 3: Reference test** | | |
| a) Is the reference test likely to correctly classify the target condition? | No | Low |
| b) Were the reference test results interpreted without knowledge of the results of the index standard? | Yes | Low |
| c) Did animals receive the same reference standard irrespective of the index test result? | Yes | Low |
| d) Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)? | Yes | Low |
| e) Did the study provide a clear definition of what was considered to be a positive result? | Yes | Low |
| f) Had test operators had appropriate training/experience? | Yes | Low |
| g) Were data on observer variation reported and within an acceptable range? | NA | NA |
| | | |
| **Domain 4: Flow and timing** | | |
| a) Was there an appropriate interval between index test and reference standard? | Yes | |
| b) Did all animals receive the same reference standard? | Yes | |
| c) Were withdrawn animals explained | NA | |
| d) Was treatment withheld until both the index test and reference standard were performed? | Unclear | |

## 8.9. Appendix 9: Specific details of test accuracy reported for each comparison within a study

Table 8-7: Specific details of test accuracy reported for each comparison within a study.

| Author | Index test | No. units exclude from analysis | Exclusion justification | Se | Sp | TP | FP | TN | FN | Specific settings |
|---|---|---|---|---|---|---|---|---|---|---|
| **Lameness detection** | | | | | | | | | | |
| Leach et al. (2009) | Visual observation of two or more lameness indicators | None reported | NA | 0.68 | 0.96 | 25 | 59 | 2 | 12 | Cows housed in tie-stalls |
| Thomsen (2009) | Observation of an arched back | None reported | NA | 0.5 | 0.86 | 55 | 295 | 48 | 56 | Cows housed in free-stalls |
| **Foot lesion detection** | | | | | | | | | | |
| Alsaaod and Buscher (2012) Comparison 1 | Infra-red thermography | None reported | NA | 0.86 | 0.56 | NC | NC | NC | NC | 0.64C threshold, pre-trimming on clean hind feet (washed), IRT camera set at fixed position and images captured at 0.5m distance, image solution 1280x1024 pixels, emissivity value set at 0.98. |
| Alsaaod and Buscher (2012) Comparison 2 | Infra-red thermography | None reported | NA | 0.81 | 0.83 | NC | NC | NC | NC | 1.09C threshold, IRT taken post trimming on clean hind (washed), IRT camera set at fixed position and images captured at 0.5m distance, image solution 1280x1024 pixels, emissivity value set at 0.98. |
| Bicalho et al. (2007a) Study 1, Comparison 1 | Force plate system | 10 | Cow has missing data | 0.36 | 0.85 | 20 | 393 | 67 | 38 | Lameness threshold SLS >31 |
| Bicalho et al. (2007a) Study 1, Comparison 2 | Force plate system | 10 | Cow has missing data | 0.33 | 0.87 | 19 | 401 | 59 | 39 | Lameness threshold SLS >32 |

| Author | Index test | No. units exclude from analysis | Exclusion justification | Se | Sp | TP | FP | TN | FN | Specific settings |
|---|---|---|---|---|---|---|---|---|---|---|
| Bicalho et al. (2007a) Study 1, Comparison 3 | Force plate system | 10 | Cow has missing data | 0.33 | 0.90 | 19 | 412 | 48 | 39 | Lameness threshold SLS >33 |
| Bicalho et al. (2007a) Study 1, Comparison 4 | Force plate system | 10 | Cow has missing data | 0.28 | 0.90 | 16 | 416 | 44 | 42 | Lameness threshold SLS >34 |
| Bicalho et al. (2007a) Study 1, Comparison 5 | Force plate system | 10 | Cow has missing data | 0.24 | 0.92 | 14 | 421 | 39 | 44 | Lameness threshold SLS >35 |
| Bicalho et al. (2007a) Study 1, Comparison 6 | Force plate system | 10 | Cow has missing data | 0.24 | 0.92 | 14 | 424 | 36 | 44 | Lameness threshold SLS >36 |
| Bicalho et al. (2007a) Study 1, Comparison 7 | Force plate system | 10 | Cow has missing data | 0.24 | 0.92 | 14 | 424 | 36 | 44 | Lameness threshold SLS >37 |
| Bicalho et al. (2007a) Study 1, Comparison 8 | Force plate system | 10 | Cow has missing data | 0.24 | 0.94 | 14 | 431 | 29 | 44 | Lameness threshold SLS >38 |
| Bicalho et al. (2007a) Study 1, Comparison 9 | Force plate system | 10 | Cow has missing data | 0.22 | 0.94 | 13 | 432 | 28 | 45 | Lameness threshold SLS >39 |
| Bicalho et al. (2007a) Study 1, Comparison 10 | Force plate system | 10 | Cow has missing data | 0.21 | 0.95 | 12 | 436 | 24 | 46 | Lameness threshold SLS >40 |
| Bicalho et al. (2007a) Study 2, Comparison 1 | Locomotion scoring system (scale 1-5) | 10 | Cow has missing data | 0.94 | 0.28 | 55 | 131 | 329 | 3 | Lameness threshold VLS >1. |
| Bicalho et al. (2007a) Study 2, Comparison 2 | Locomotion scoring system (scale 1-5) | 10 | Cow has missing data | 0.67 | 0.85 | 39 | 389 | 71 | 19 | Lameness threshold VLS >2. |

| Author | Index test | No. units exclude from analysis | Exclusion justification | Se | Sp | TP | FP | TN | FN | Specific settings |
|---|---|---|---|---|---|---|---|---|---|---|
| Bicalho et al. (2007a) Study 2, Comparison 3 | Locomotion scoring system (scale 1-5) | 10 | Cow has missing data | 0.24 | 0.98 | 14 | 451 | 9 | 44 | Lameness threshold VLS >3. |
| Bicalho et al. (2007a) Study 2, Comparison 4 | Locomotion scoring system (scale 1-5) | 10 | Cow has missing data | ?? | 0.99 | NC | NC | NC | NC | Lameness threshold VLS >4. |
| Main et al. (2012) Comparison 1 | Infra-red thermography | None reported | NA | 0.72 | 0.73 | 100 | 107 | 40 | 39 | Hoof not washed, 25.5 C threshold, distance to spot size ratio 12:1, accuracy ±1.0 per cent |
| Main et al. (2012) Comparison 2 | Infra-red thermography | None reported | NA | 0.78 | 0.78 | 108 | 115 | 32 | 31 | Hoof not washed, 25.25 C threshold, distance to spot size ratio 12:1, accuracy ±1.0 per cent |
| Stokes et al. (2012a) Comparison 1 | Infra-red thermography | None reported | NA | 0.80 | 0.73 | 66 | 60 | 22 | 16 | Hoof not washed, 27C threshold, thermal images were taken from the plantar aspect of each foot at the pastern |
| Stokes et al. (2012a) Comparison 2 | Infra-red thermography | None reported | NA | 0.91 | 0.54 | 75 | 44 | 38 | 7 | Foot washed with high pressure hose and dried with paper towel. 22C threshold, thermal images were taken were taken from the plantar aspect of each foot at the pastern |
| Stokes et al. (2012a) Comparison 3 | Infra-red thermography | None reported | NA | 0.93 | 0.49 | 76 | 40 | 42 | 6 | Cleaned foot. 21C threshold, thermal images were taken from the plantar aspect of each foot at the pastern |
| **Sole ulcer detection** | | | | | | | | | | |
| Chapinal et al. (2009) Study 1 | Observation of abduction/adduction | 28 | Primiparous cows (n=25) because few had | 0.44 | 0.55 | 6 | 22 | 18 | 7 | Cows were videotaped and then assessed using a 100-unit |

| Author | Index test | No. units exclude from analysis | Exclusion justification | Se | Sp | TP | FP | TN | FN | Specific settings |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | sole lesions; cow with a lesion that was not specified in the list (n=3) | | | | | | | continuous scale, where 0 represented a sound gait attribute and 100 represented the most extreme example possible. |
| Chapinal et al. (2009) Study 2 | Observation of back arch | 28 | Primiparous cows (n=25) because few had sole lesions; cow with a lesion that was not specified in the list (n=3) | 0.68 | 0.46 | 9 | 18 | 22 | 4 | Cows were videotaped and then assessed using a 100-unit continuous scale, where 0 represented a sound gait attribute and 100 represented the most extreme example possible. |
| Chapinal et al. (2009) Study 3 | Observation of head bob | 28 | Primiparous cows (n=25) because few had sole lesions; cow with a lesion that was not specified in the list (n=3) | 0.62 | 0.71 | 8 | 28 | 12 | 5 | Cows were videotaped and then assessed using a 100-unit continuous scale, where 0 represented a sound gait attribute and 100 represented the most extreme example possible. |
| Chapinal et al. (2009) Study 4 | Observation of tracking up | 28 | Primiparous cows (n=25) because few had sole lesions; cow with a lesion that was not specified in the list (n=3) | 0.60 | 0.38 | 8 | 15 | 25 | 5 | Cows were videotaped and then assessed using a 100-unit continuous scale, where 0 represented a sound gait attribute and 100 represented the most extreme example possible. |
| Chapinal et al. (2009) Study 5 | Observation of joint flexion | 28 | Primiparous cows (n=25) because few had sole lesions; cow with a lesion that was not specified in the list (n=3) | 0.70 | 0.54 | 9 | 22 | 18 | 4 | Cows were videotaped and then assessed using a 100-unit continuous scale, where 0 represented a sound gait attribute and 100 represented |

| Author | Index test | No. units exclude from analysis | Exclusion justification | Se | Sp | TP | FP | TN | FN | Specific settings |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | the most extreme example possible. |
| Chapinal et al. (2009) Study 6 | Observation of asymmetric gait | 28 | Primiparous cows (n=25) because few had sole lesions; cow with a lesion that was not specified in the list (n=3) | 0.70 | 0.54 | 9 | 22 | 18 | 4 | Cows were videotaped and then assessed using a 100-unit continuous scale, where 0 represented a sound gait attribute and 100 represented the most extreme example possible. |
| Chapinal et al. (2009) Study 7 | Observation of reluctance to bear weight | 28 | Primiparous cows (n=25) because few had sole lesions; cow with a lesion that was not specified in the list (n=3) | 0.75 | 0.54 | 10 | 22 | 18 | 3 | Cows were videotaped and then assessed using a 100-unit continuous scale, where 0 represented a sound gait attribute and 100 represented the most extreme example possible. |
| **Digital dermatitis detection** | | | | | | | | | | |
| Alsaaod et al. (2014) Comparison 1 | Infra-red thermography | None reported | NA | 0.86 | 0.56 | 33 | 16 | 8 | 4 | Hind foot not washed, IRT held in hand at distance 0.5m, in a lateral dorsal-mediodistal oblique direction, perpendicular to the abaxial claw, images of the medial claw medial claw the camera was similarly held but perpendicular to axial claw wall, 0.99˚C threshold, precision +/- 0.01, Emissivity 0.95 |
| Alsaaod et al. (2014) Comparison 2 | Infra-red thermography | None reported | NA | 0.81 | 0.83 | 3 | 15 | 9 | 2 | Front & Hind feet, not washed, lateral claw IRT held in hand at distance 0.5m, in a lateral dorsal-mediodistal oblique |

| Author | Index test | No. units exclude from analysis | Exclusion justification | Se | Sp | TP | FP | TN | FN | Specific settings |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | direction, perpendicular to the abaxial claw, medial claw the camera was similarly held but perpendicular to axial claw wall, 0.85˚C threshold, precision +/- 0.01, Emissivity 0.95 |
| Relun et al. (2011) | Visual inspection in milk parlour with swivelling mirror and powerful headlamp | None reported | NA | 0.90 | 0.80 | 195 | 214 | 53 | 22 | Hind feet were cleaned with a medium-pressure water hose |
| Rodriguez-Lainz et al. (1998) | Visual inspection in milk parlour | 2 | Sold before inspection in chute | 0.72 | 0.99 | 23 | 84 | 1 | 9 | Feet washed |
| Stokes et al. (2012b) Study 1 | Visual inspection in milk parlour | None reported | NA | 1.00 | 0.99 | NC | NC | NC | NC | Hind feet up to the dew claws were cleaned with a medium pressure hose and then dried with a paper towel. |
| Stokes et al. (2012b) Study 2 | Visual inspection using borescope | None reported | NA | 1 | 1 | NC | NC | NC | NC | Hind feet up to the dew claws were cleaned with a medium pressure hose and then dried with a paper towel. |
| Thomsen et al. (2008a) | Visual inspection in milk parlour | None reported | NA | 0.65 | 0.84 | 147 | 472 | 88 | 79 | Rear legs of all cows were washed using a water hose. The observer used a flashlight to ensure adequate light for the evaluation and a dictaphone to record the scorings |

TP: true positive, TN: true negative, FP: false positive, FN: false negative, NA: not applicable, NC: could not be calculated, IRT: infra-red thermograph; SLS: StepMatrix locomotion score; VLS: visual locomotion score

## 8.10. Appendix 10: Animal ethics approval for Chapter 4

THE UNIVERSITY OF QUEENSLAND

*PLEASE KEEP THIS FORM IT IS YOUR RECORD OF YOUR AEC APPROVAL NUMBER*

Ms Ann Higgins
**Animal Welfare Coordinator**
Research and Research Training Division
Cumbrae Stewart Building (72)
St Lucia Q 4072
Ph: (07) 3365 2713 Fax: (07) 3365 4455
Email: a.higgins@research.uq.edu.au

ANIMAL ETHICS APPROVAL CERTIFICATE ***Date: 19-Apr-2012***

Dear Mr John Al-Alawneh, Veterinary Science

The following project: *Concordance of farm workers and veterinary diagnoses and treatment of lameness lesions in a dairy herd*

Requesting funding from (Grant Awarding Body):- involves animal experimentation. It has been reviewed and ethical clearance obtained from the University Animal Ethics Committee (Production and Companion Animal).

**AEC Approval Number:**

SVS/082/12 **Previous AEC**

**Number:**

**Approval Duration:** 20-Apr-2012 to 20-Apr-2015

**Permit(s):**

| SUBSPECIES | STRAIN | CLASS | GENDER | SOURCE | AMOUNT |
|---|---|---|---|---|---|
| Cattle | | Adults | Mix | UQ | **990** |

**Proviso(s):**

---

**Please note the animal numbers supplied on this certificate are the total allocated for the approval duration**

**Please use this Approval Number:**

1. When ordering animals from Animal Breeding Houses

2. For labelling of all animal cages or holding areas. In addition please include on the label, Chief Investigator's name and contact phone number.
3. When you need to communicate with this office about the project.

It is a condition of this approval that all animal usage details be made available to Animal House OIC. (UAEC Ruling 14/12/2001)

**This certificate supercedes all preceeding certificates for this project (i.e. those certificates dated before 19-Apr-2012**

## 8.11. Appendix 11: Lameness data collection forms

a) Lameness data collection form used by the veterinarians.

**LAMENESS DATA CAPTURE FORM**

Circle one: Farm-vet / Remote-vet

Animal ID Ear Tag______ Tatoo________ FARM ID________________

Examination Date DD___MM___YY___ Body Score_______ Weight____________ Kg

Date of Birth DD__MM__YY__ Sex: Male ¦ Female ¦ Steer¦ Date of Disposal DD__MM__YY__

Reason for Disposal Lame ¦ Production ¦ Infertility ¦ Mastitis ¦ Death ¦ Other__________

(1) LAMENESS SCORE

1 NORMAL

2 SLIGHT ABNORMALITY
Uneven gait, stiff, tender.

3 SLIGHT LAMENESS
Moderate and consistent lameness

4 OBVIOUS LAMENESS
Obvious lameness affecting behavior

5 SEVERE LAMENESS
Very marked lameness.

(2) LIMB/CLAW AFFECTED

| LEFT FORE | | RIGHT FORE | | LEFT HIND | | RIGHT HIND | |
|---|---|---|---|---|---|---|---|
| 12 | | 34 | | 56 | | 78 | |
| LAT | MED | MED | LAT | LAT | MED | MED | LAT |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

(3) CLASSIFICATION OF LESION

0 Lesions of sole
01. Hemorrhage of sole
02. Sole ulcer
03. White line disease
04. Heel erosion
05. Worn/bruised sole
06. Double sole
07. Sole trauma
08. Sole abscess

9 Interdigital lesions
10. Foot rot/foul
11. Interdig dermatitis
12. Interdig hyperplasia
13. Foreign body

14 Digital Lesions
20. Digital dermatitis
21. Septic Arthritis
22. Retroartic abscess

23 Fissures of the Claw Wall
30. Vert fissure Type I
31. Vertical fissure Type II
32. Vertical fissure Type III
33. Vertical fissure Type IV
34. Horizontal Groove
(Severity = cm)
38. Hor fissure/thimble
39. Hor fiss broken toe

47 Abnormalities of Wall
40. Normal overgrowth
41. Slipper foot (Chr Lam
42. Corkscrew claw
43. Scissor claw
44. Hook claw
45. Reaction Ridge
(Severity = cm)
46. Change Coronary Band

48 Lesion of Proximal Limb
50. Fracture/rupture
51. Hematoma

(7) BODY REGION
01. Scapula or Pelvis
02. Humerus or Femur
03. Radius or Tibia
04. Carpus of Tarsus
05. Metacarpus or Metatarsus
06. Proximal Phalanx
07. Intermediate Phalanx
08. Distal Phalanx
09. Distal Sesamoid
10. Interdigital

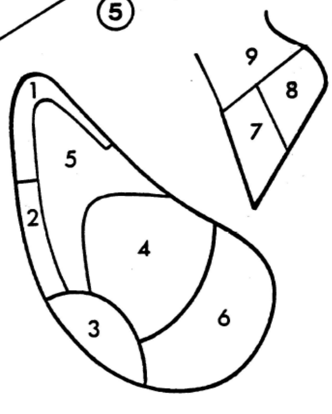
(8) TISSUE
01. Hoof Sole
02. Hoof Wall
03. Hoof Heel
04. Bone
05. Muscle
06. Joint
07. Skin
08. Nerve
09. Tendon
10. Ligament

| PHOTOGRAPH | |
|---|---|
| YES | NO |
| MARK | cm |

| | LESION NUMBER 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| TISSUE | | | | |
| BODY REGION | | | | |
| LIMB/CLAW | | | | |
| SEVERITY OF LESION | | | | |
| CLASSIFICATION OF LESION | | | | |
| ZONE OF CLAW | | | | |

(4) SEVERITY OF LESION
1. Mild, Trace.
2. Distinct diagnostic sign
3. Marked clinical lesion
4. Complicated or serious or infected

(5) ZONE OF CLAW




(6) TREATMENT
01. Topical
10. Penicillin G Procaine
11. Penicillin G Benzathine
12. Lincomycin
13. Tetracycline
14. Oxytetracycline
15. Erythromycin
16. Tylosin
30. Sulfadimethoxine
31. Sulfachlorpyridazine
32. Sulfadiazine
40. Analgesic
45. Phenylbutazone
46. Dexamethasone
47. Prednisolone
50. Bandage/Boot
60. Amputation
61. Resection
62. Arthrodesis
70. Hoof Trim
71. Block/lift
90. Veterinarian
91. Stockman
92. Technician/student
93.Pain Mang,AB,
94.Pain Mang,Trim,AB
95.Trim,AB
96.Pain Mang,Trim
97.Penicillin-Farm
98.Other

Treatment: Date of Recovery DD__MM__YY__

Drug Used______________ Dosage__________ Frequency per day______ #Days_____

Drug Use______________ Dosage__________ Frequency per day______ #Days_____

Other Treatments______________________________________

b) Lameness data collection form used by the dairy farmer.

## *LAMENESS DATA CAPTURE FORM*

Examiner's name or code:--------------------------- Position:-------------------- Age:---------- Sex:-----------------

Experience in dairy/cattle (years):---------------------- Highest qualifications:-------------------------------------

*Animal ID Ear Tag______ Tatoo________ FARM ID____________________*
*Examination Date DD___MM___YY___ Body Score______ Weight______________ Kg*
*Date of Birth DD__MM__YY__ Sex: Male ¦ Female ¦ Steer¦ Date of Disposal DD__MM__YY__*
*Reason for Disposal Lame ¦ Production ¦ Infertility ¦ Mastitis ¦ Death ¦ Other___________*

(1) *LAMENESS SCORE* [ ]

1.Normal
2.Slight abnormality (uneven gait, stiff, tender)
3.Slight lameness (moderate and consistent lameness)
4.Obvious lameness (obvious lameness affecting behaviour)
5.Severe lameness (very marked lameness)

General comments

(8) *TISSUE*
1.Sole
2.Wall
3.Heel
4.Bone
5.Muscle
6.Joint

| PHOTOGRAPH | |
|---|---|
| YES | NO |

(2) *LIMB/CLAW AFFECTED*

| LEFT FORE | | RIGHT FORE | | LEFT HIND | | RIGHT HIND | |
|---|---|---|---|---|---|---|---|
| LAT | MED | MED | LAT | LAT | MED | MED | LAT |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

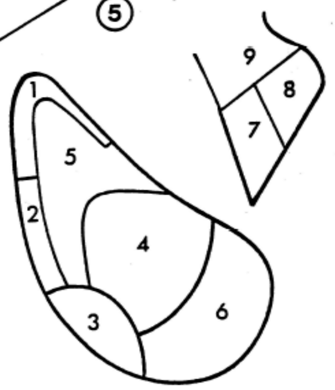
| LESION NUMBER | | | |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

(4) *SEVERITY OF LESION*
1.Mild, Trace
2.Distinct diag sign
3.Marked Clin lesi.
4.Complicated or infected

(3) *CLASSIFICATION OF LESION*

**0.lesions of sole**
1.Haemorrhage of the sole
2.Sole ulcer
3.White line disease
4.Heel erosion
5.Worn or bruised sole
6.Double sole
7.Sole trauma
8.Sole abscess
**9.Interdigital lesions**
10.Foot rot/ foul
13.Foreign body
**14.Digital lesions**
20.Digital dermatitis
**23.Fissures of the claw wall**
30.Vert fissu Typ1
38.Horz fissu
**47.Abnormality of wall**
40.Normal overgrowth
41.Slipper foot
42.Corkscrew claw
43.Scissor claw

(5) *ZONE OF CLAW*




(6) *TREATMENT*
1.Tropical
14.Oxytetracycline
16.Tylosin
32.Sulfadiazine
40.Analgesic
50.Bandage
70.Hoof trim
71.Block/lift
90.Veterinarian
93.Pain Mang,AB,
94.Pain Mang,Trim,AB
95.Trim,AB
96.Pain Mang,Trim
97.Penicillin-Farm
98.Other

*Treatment: Date of Recovery DD__MM__YY__*
*DrugUsed______________ Dosage__________ Frequencyperday_____ #Days_____*

*Drug Use______________ Dosage__________ Frequency perday_____ #Days_____*
*Other Treatments_________________________________________*

## 8.12. Appendix 12: 2 x 2 matrices between farm veterinarian and dairy farmer

Table 8-8: 2 x 2 matrix for the variable limb affected, category left fore-limb.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 3 | 0 | 3 |
| **-** | 0 | 70 | 70 |
| **Total** | 3 | 70 | 73 |

Table 8-9: 2 x 2 matrix for the variable limb affected, category right fore-limb.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 3 | 0 | 3 |
| **-** | 0 | 70 | 70 |
| **Total** | 3 | 70 | 73 |

Table 8-10: Figure x: 2 x 2 matrix for the variable limb affected, category left hind-limb.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 35 | 0 | 35 |
| **-** | 2 | 36 | 38 |
| **Total** | 37 | 36 | 73 |

Table 8-11: 2 x 2 matrix for the variable limb affected, category right fore-limb.

| | **Dairy Farmer** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 35 | 1 | 36 |
| **-** | 0 | 37 | 37 |
| **Total** | 35 | 38 | 73 |

Table 8-12: 2 x 2 matrix for the variable body region, category intermediate phalanx.

| | **Dairy Farmer** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 3 | 0 | 3 |
| **-** | 0 | 69 | 69 |
| **Total** | 3 | 69 | 72 |

Table 8-13: 2 x 2 matrix for the variable body region, category distal phalanx.

| | **Dairy Farmer** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 46 | 5 | 51 |
| **-** | 2 | 19 | 21 |
| **Total** | 48 | 24 | 72 |

Table 8-14: 2 x 2 matrix for the variable body region, category interdigital.

| | **Dairy Farmer** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 18 | 6 | 24 |
| **-** | 0 | 48 | 48 |
| **Total** | 18 | 54 | 72 |

Table 8-15: 2 x 2 matrix for the variable tissue, category hoof sole.

| | **Dairy Farmer** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 23 | 4 | 27 |
| **-** | 2 | 43 | 45 |
| **Total** | 25 | 47 | 72 |

Table 8-16: 2 x 2 matrix for the variable tissue, category hoof wall.

| | **Dairy Farmer** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 3 | 4 | 7 |
| **-** | 1 | 64 | 65 |
| **Total** | 4 | 68 | 72 |

Table 8-17: 2 x 2 matrix for the variable tissue, category hoof heel.

| | **Dairy Farmer** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 12 | 7 | 27 |
| **-** | 1 | 52 | 45 |
| **Total** | 25 | 47 | 72 |

Table 8-18: 2 x 2 matrix for the variable tissue, category skin.

| | **Dairy Farmer** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 31 | 7 | 38 |
| **-** | 0 | 34 | 34 |
| **Total** | 31 | 41 | 72 |

Table 8-19: 2 x 2 matrix for the variable tissue, category joint.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 0 | 0 | 0 |
| **-** | 1 | 71 | 72 |
| **Total** | 1 | 71 | 72 |

Table 8-20: 2 x 2 matrix for the variable diagnosis aggregated, category lesions of the sole.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 30 | 14 | 44 |
| **-** | 6 | 22 | 28 |
| **Total** | 36 | 36 | 72 |

Table 8-21: 2 x 2 matrix for the variable diagnosis aggregated, category interdigital lesions.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 19 | 17 | 36 |
| **-** | 4 | 32 | 36 |
| **Total** | 23 | 49 | 72 |

Table 8-22: 2 x 2 matrix for the variable diagnosis aggregated, category digital lesions.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 1 | 1 | 2 |
| **-** | 0 | 70 | 70 |
| **Total** | 1 | 71 | 72 |

Table 8-23: 2 x 2 matrix for the variable diagnosis aggregated, category fissures of the claw.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 4 | 5 | 9 |
| **-** | 3 | 60 | 63 |
| **Total** | 7 | 65 | 72 |

Table 8-24: 2 x 2 matrix for the variable diagnosis aggregated, category abnormalities of the wall.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 0 | 1 | 1 |
| **-** | 6 | 65 | 71 |
| **Total** | 6 | 66 | 72 |

Table 8-25: 2 x 2 matrix for the variable diagnosis aggregated, category lesions of the proximal limb.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 5 | 0 | 5 |
| **-** | 17 | 50 | 67 |
| **Total** | 22 | 50 | 72 |

Table 8-26: 2 x 2 matrix for the variable treatment aggregated, category topical therapy only.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 21 | 19 | 40 |
| **-** | 1 | 31 | 32 |
| **Total** | 22 | 50 | 72 |

Table 8-27: 2 x 2 matrix for the variable treatment aggregated, category systemic antibiotic.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 2 | 0 | 2 |
| **-** | 3 | 67 | 70 |
| **Total** | 5 | 67 | 72 |

Table 8-28: 2 x 2 matrix for the variable treatment aggregated, category pain relief.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 7 | 3 | 10 |
| **-** | 1 | 61 | 62 |
| **Total** | 8 | 64 | 72 |

Table 8-29: 2 x 2 matrix for the variable treatment aggregated, category trim.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 29 | 11 | 40 |
| **-** | 3 | 29 | 32 |
| **Total** | 32 | 40 | 72 |

Table 8-30: 2 x 2 matrix for the variable treatment aggregated, category block/lift.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 4 | 3 | 7 |
| **-** | 0 | 65 | 65 |
| **Total** | 4 | 68 | 72 |

Table 8-31: 2 x 2 matrix for the variable treatment aggregated, category surgery.

| | Dairy Farmer | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 1 | 3 | 4 |
| **-** | 2 | 66 | 68 |
| **Total** | 3 | 69 | 72 |

## 8.13. Appendix 13: 5 x 5 matrix for the variable locomotion score

Table 8-32: 5 x 5 matrix for the variable locomotion score

| | DF LCS | | | | | |
|---|---|---|---|---|---|---|
| FV LCS | 1 | 2 | 3 | 4 | 5 | Total |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 2 | 2 | 4 | 0 | 0 | 0 | 6 |
| 3 | 5 | 6 | 13 | 4 | 1 | 29 |
| 4 | 2 | 1 | 8 | 23 | 1 | 35 |
| 5 | 0 | 0 | 1 | 0 | 1 | 2 |
| Total | 10 | 11 | 22 | 27 | 3 | 73 |

## 8.14. Appendix 14: 4 x 4 matrix for the variable maximum lesion severity

Table 8-33: 4 x 4 matrix for the variable maximum lesion severity

| | DF maximum lesion severity | | | | | |
|---|---|---|---|---|---|---|
| FV maximum lesion severity | 1 | 2 | 3 | 4 | No lesion | Total |
| 1 | 4 | 0 | 0 | 1 | 0 | 5 |
| 2 | 6 | 8 | 4 | 2 | 2 | 22 |
| 3 | 4 | 8 | 5 | 7 | 5 | 29 |
| 4 | 0 | 9 | 3 | 4 | 0 | 16 |
| No lesion | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 14 | 25 | 12 | 14 | 7 | 72 |

## 8.15. Appendix 15: 2 X 2 matrices between farm veterinarian and remote veterinarian

Table 8-34: 2 x 2 matrix for the variable body region, category intermediate phalanx.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 3 | 0 | 3 |
| **-** | 0 | 70 | 70 |
| **Total** | 3 | 70 | 73 |

Table 8-35: 2 x 2 matrix for the variable body region, category distal phalanx.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 52 | 0 | 52 |
| **-** | 8 | 13 | 21 |
| **Total** | 60 | 13 | 77 |

Table 8-36: 2 x 2 matrix for the variable body region, category distal sesamoid.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 0 | 0 | 0 |
| **-** | 1 | 72 | 73 |
| **Total** | 1 | 72 | 73 |

Table 8-37: 2 x 2 matrix for the variable body region, category interdigital.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 15 | 9 | 24 |
| **-** | 0 | 49 | 49 |
| **Total** | 15 | 58 | 73 |

Table 8-38: 2 x 2 matrix for the variable tissue, category hoof sole.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 29 | 0 | 29 |
| **-** | 7 | 37 | 44 |
| **Total** | 36 | 37 | 73 |

Table 8-39: 2 x 2 matrix for the variable tissue, category hoof wall.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 5 | 2 | 7 |
| **-** | 1 | 65 | 66 |
| **Total** | 6 | 67 | 73 |

Table 8-40: 2 x 2 matrix for the variable tissue, category hoof heel.

| | Remote Veterinarian | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 15 | 5 | 20 |
| **-** | 3 | 50 | 53 |
| **Total** | 18 | 55 | 73 |

Table 8-41: 2 x 2 matrix for the variable tissue, category skin.

| | Remote Veterinarian | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 32 | 5 | 37 |
| **-** | 1 | 35 | 36 |
| **Total** | 33 | 40 | 73 |

Table 8-42: 2 x 2 matrix for the variable tissue, category joint.

| | Remote Veterinarian | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 1 | 0 | 1 |
| **-** | 0 | 72 | 72 |
| **Total** | 1 | 72 | 73 |

Table 8-43: 2 x 2 matrix for the variable diagnosis aggregated, category lesions of the sole.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 41 | 3 | 44 |
| **-** | 9 | 20 | 29 |
| **Total** | 50 | 23 | 73 |

Table 8-44: 2 x 2 matrix for the variable diagnosis aggregated, category interdigital lesions.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 28 | 8 | 36 |
| **-** | 2 | 35 | 37 |
| **Total** | 30 | 43 | 73 |

Table 8-45: 2 x 2 matrix for the variable diagnosis aggregated, category digital lesions.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 1 | 1 | 2 |
| **-** | 1 | 70 | 71 |
| **Total** | 2 | 71 | 73 |

Table 8-46: 2 x 2 matrix for the variable diagnosis aggregated, category fissures of the claw.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 4 | 6 | 11 |
| **-** | 2 | 60 | 62 |
| **Total** | 6 | 66 | 73 |

Table 8-47: 2 x 2 matrix for the variable diagnosis aggregated, category abnormalities of the wall.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 1 | 1 | 2 |
| **-** | 0 | 71 | 71 |
| **Total** | 1 | 72 | 73 |

Table 8-48: 2 x 2 matrix for the variable diagnosis aggregated, category lesions of the proximal limb.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 0 | 0 | 0 |
| **-** | 1 | 72 | 73 |
| **Total** | 1 | 72 | 73 |

Table 8-49: 2 x 2 matrix for the variable treatment aggregated, category topical therapy only.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 39 | 1 | 40 |
| **-** | 7 | 26 | 33 |
| **Total** | 46 | 27 | 73 |

Table 8-50: 2 x 2 matrix for the variable treatment aggregated, category systemic antibiotic.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 1 | 1 | 2 |
| **-** | 0 | 71 | 71 |
| **Total** | 1 | 72 | 73 |

Table 8-51: 2 x 2 matrix for the variable treatment aggregated, category pain relief.

| | **Remote Veterinarian** | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 10 | 0 | 10 |
| **-** | 1 | 62 | 63 |
| **Total** | 11 | 62 | 73 |

Table 8-52: 2 x 2 matrix for the variable treatment aggregated, category trim.

| | Remote Veterinarian | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 31 | 9 | 40 |
| **-** | 1 | 32 | 33 |
| **Total** | 32 | 41 | 73 |

Table 8-53: 2 x 2 matrix for the variable treatment aggregated, category block/lift.

| | Remote Veterinarian | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 5 | 2 | 7 |
| **-** | 0 | 66 | 66 |
| **Total** | 5 | 68 | 73 |

Table 8-54: 2 x 2 matrix for the variable treatment aggregated, category surgery.

| | Remote Veterinarian | | |
|---|---|---|---|
| **Farm Veterinarian** | **+** | **-** | **Total** |
| **+** | 4 | 1 | 7 |
| **-** | 1 | 67 | 66 |
| **Total** | 5 | 68 | 73 |

## 8.16. Appendix 16: 4 x 4 matrix for the variable severity

Table 8-55: 4 x 4 matrix for the variable maximum lesion severity

| | RV maximum lesion severity | | | | |
|---|---|---|---|---|---|
| FV maximum lesion severity | 1 | 2 | 3 | 4 | Total |
| 1 | 5 | 0 | 0 | 0 | 5 |
| 2 | 4 | 16 | 2 | 0 | 22 |
| 3 | 1 | 11 | 16 | 1 | 29 |
| 4 | 2 | 4 | 3 | 8 | 17 |
| Total | 12 | 31 | 21 | 9 | 73 |

## 8.17. Appendix 17: Ethics approval for Chapter 5

THE UNIVERSITY OF QUEENSLAND

**Institutional Human Research Ethics Approval**

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| | |
|---|---|
| **Project Title:** | Understanding Dairy Farmer Intentions to Make Improvements to their Current Management Practices of Foot Lesions Causing Lameness in Dairy Cows |
| **Chief Investigator:** | Ms Kate Chaplin |
| **Supervisor:** | Dr Tamsin Barnes, Dr John Wright, Dr Ahmad Rabiee |
| **Co-Investigator(s):** | Dr Tamsin Barnes, Dr John Wright, Dr Ahmad Rabiee |
| **School(s):** | School of Veterinary Science |
| **Approval Number:** | 2016001140 |
| **Granting Agency/Degree:** | RSPCA Australia |
| **Duration:** | 28th February 2017 |

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**Comments/Conditions:**

Expedited Review - Low Risk

- Participant Information Sheet, 25/07/2016
- Consent Form, 25/07/2016
- Gatekeeper letter, 25/07/2016
- Elicitation Questionnaire, 25/07/2016

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Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

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**Name of responsible Committee:**
**University of Queensland Human Research Ethics Committee A**
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

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**Name of Ethics Committee representative:**
**Professor Emerita Gina Geffen**
**Chairperson**
**University of Queensland Human Research Ethics Committee A**
**Registration: EC00456**

G. Geffen

Signature ______________________________ Date 18/10/2016

THE UNIVERSITY OF QUEENSLAND

# Institutional Human Research Ethics Approval

| | |
|---|---|
| **Project Title:** | Understanding Dairy Farmer Intentions to Make Improvements to their Current Management Practices of Foot Lesions Causing Lameness in Dairy Cows - 27/02/2017 - AMENDMENT |
| **Chief Investigator:** | Ms Kate Chaplin |
| **Supervisor:** | Dr Tamsin Barnes, Dr John Wright, Dr Ahmad Rabiee |
| **Co-Investigator(s):** | Dr Tamsin Barnes, Dr John Wright, Dr Ahmad Rabiee |
| **School(s):** | School of Veterinary Science |
| **Approval Number:** | 2016001140 |
| **Granting Agency/Degree:** | RSPCA Australia |
| **Duration:** | 28th February 2018 |

**Comments/Conditions:**

- Amendment Application
- Dairy NSW Gatekeeper Letter, 10/02/2017
- AusDairyL Gatekeeper Letter, 10/02/2017
- DairySA Gatekeeper Letter, 23/02/2017
- Scibus & Cows-R-Us Gatekeeper Letter, 10/02/2017
- South Coast & Highlands Dairy Industry Group Inc. Gatekeeper Letter, 22/02/2017
- Norco Mild Supply Gatekeeper Letter, 17/02/2017
- Dairy Farmers Milk Co-operative Gatekeeper Letter, 10/02/2017
- Participant Information Sheet, 27/02/2017
- Questionnaire Dairy Farmers, 27/02/2017

Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

**Name of responsible Committee:**
**University of Queensland Human Research Ethics Committee B**
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

**Name of Ethics Committee representative:**
**Dr. Frederick Khafagi**
**Chairperson**
**University of Queensland Human Research Ethics Committee**
**Registration: EC00457**

Signature ____________________ Date 11/04/2017

## 8.18. Appendix 18: Elicitation questionnaire used for stage 1 of study

**Understanding dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness in dairy cows**

**Instructions**

Please take a few minutes to respond to the questions below regarding your thoughts on making improvements to your current management practices of foot lesions causing lameness in your dairy herd over the next 12 months.

In terms of making improvements, consider what changes you might make to your current management practices. This includes any new or improved action that you might start doing over the next year that can:

1. Improve your ability to detect cows with foot lesions in your herd.
2. Improve the ability to make a correct diagnosis of a foot lesion in a cow.
3. Reduce the overall occurrence of foot lesions in your herd.
4. Shorten the amount of time that it takes for a cow to recover from a foot lesion.

The following provides some examples of changes that you might consider to start doing over the next 12 months:

**Current management practice:** No hoof trimming performed; maintenance hoof trimming performed only once per year; hoof trimming performed only as required, i.e. for treatment purposes.
**Change in management practice:** Conduct maintenance hoof trimming twice per year, i.e., every 6 months.

**Current management practice:** Currently no use of a locomotion scoring system.
**Change in management practice:** Use a locomotion scoring system daily, before or after milking, to screen for lame cows.

**Current management practice:** Holding off looking at a lame cow until tomorrow; holding off looking at a lame cow until it 'gets worse'.
**Change in management practice:** Looking at a lame cow for foot lesions immediately upon noticing it is lame.

**Current management practice:** Staff do not receive training regarding the care of foot lesions and lameness in dairy cows (this includes attendance at industry workshops).
**Change in management practice:** Fund staff attendance to relevant workshops

**Current management practice:** Not repairing track surfaces regularly, especially after heavy rainfall.
**Change in management practice:** Regularly repair track surfaces particularly after heavy rainfall (i.e. removal of sharp rocks and/or slurry).

**Current management practice:** No dietary supplements, intended to strengthen the hoof structure, are used.
**Change in management practice:** Use a dietary supplement, such as biotin, to strengthen the hoof structure.

**Questions**

In response to the following questions, please provide the thoughts that come immediately to mind. There are no right or wrong responses; we are merely interested in your personal opinions.

(1) What do you see as the advantages of improving the management of foot lesions causing lameness in your dairy herd over the next 12 months?
(2) What do you see as the disadvantages of improving the management of foot lesions causing lameness in your dairy herd over the next 12 months?
(3) What factors or circumstances would enable you to improve the management of foot lesions causing lameness in your dairy herd over the next 12 months?
(4) What factors or circumstances would make it difficult or prevent you from improving the management of foot lesions causing lameness in your dairy herd over the next 12 months?

When it comes to your decisions about improving the management of foot lesions causing lameness in your dairy herd over the next 12 months there might be individuals or groups who might think that you should, or should not do this.

(5) Are there any individuals or groups who would approve or think you should improve the management of foot lesions causing lameness in your dairy herd over the next 12 months?
(6) Are there any individuals or groups who would disapprove or think you should not improve the management of foot lesions causing lameness in your dairy herd over the next 12 months?

**<u>Thank you for your participation in this questionnaire.</u>**

## 8.19. Appendix 19: Tables of all beliefs from elicitation study

Table 8-56: Behavioural beliefs identified from the question 'What do you see as the advantages of improving the management of foot lesions causing lameness in your dairy herd over the next 12 months? Those marked 'Yes' were considered the modal salient beliefs that were used in the second, larger questionnaire.

| No. | Beliefs identified | No. dairy farmers | Included in questionnaire |
|---|---|---|---|
| 1 | Improved milk production | 20 | Yes |
| 2 | Improved welfare | 17 | Yes |
| 3 | Reduced costs (veterinarian visits, treatment/drugs) | 10 | Yes |
| 4 | Reduced culling | 8 | No |
| 5 | Prevention of lameness/less lame cows | 8 | No |
| 6 | Less use of antibiotics | 7 | No |
| 7 | Reduction in mastitis | 6 | No |
| 8 | More efficient work flow (lame cows are slow cows) | 4 | No |
| 9 | Improved reproductive performance/fertility | 2 | No |
| 10 | Better feed conversion | 2 | No |
| 11 | Earlier lameness detection | 2 | No |
| 12 | Reduction in time spent managing lame cows | 2 | No |
| 13 | Cows lame for less time | 1 | No |
| 14 | Improved knowledge and skills | 1 | No |
| 15 | Less loss of milk due to antibiotic use | 1 | No |
| 16 | Shorter duration of treatment | 1 | No |
| 17 | Tourists/visitors don't see lame cows | 1 | No |
| 18 | Good media coverage | 1 | No |
| 19 | Earlier and more effective treatment | 1 | No |

Table 8-57: Behavioural beliefs identified from the question ‘What do you see as the disadvantages of improving the management of foot lesions causing lameness in your dairy herd over the next 12 months? Those marked ‘Yes’ were considered the modal salient beliefs that were used in the second, larger questionnaire.

| No. | Beliefs identified | No. dairy farmers | Included in questionnaire |
|---|---|---|---|
| 1 | Improved milk production | 20 | Yes |
| 2 | Improved welfare | 17 | Yes |
| 3 | Reduced costs (veterinarian visits, treatment/drugs) | 10 | Yes |
| 4 | Reduced culling | 8 | No |
| 5 | Prevention of lameness/less lame cows | 8 | No |
| 6 | Less use of antibiotics | 7 | No |
| 7 | Reduction in mastitis | 6 | No |
| 8 | More efficient work flow (lame cows are slow cows) | 4 | No |
| 9 | Improved reproductive performance/fertility | 2 | No |
| 10 | Better feed conversion | 2 | No |
| 11 | Earlier lameness detection | 2 | No |
| 12 | Reduction in time spent managing lame cows | 2 | No |
| 13 | Cows lame for less time | 1 | No |
| 14 | Improved knowledge and skills | 1 | No |
| 15 | Less loss of milk due to antibiotic use | 1 | No |
| 16 | Shorter duration of treatment | 1 | No |
| 17 | Tourists/visitors don’t see lame cows | 1 | No |
| 18 | Good media coverage | 1 | No |
| 19 | Earlier and more effective treatment | 1 | No |

Table 8-58: Control beliefs identified from the question ‘What factors or circumstances would enable you to improve the management of foot lesions causing lameness in your dairy herd over the next 12 months?’ Those marked ‘Yes’ are considered the modal salient beliefs that will be used in the second, larger questionnaire.

| No. | Beliefs identified | No. dairy farmers | Include in questionnaire |
|---|---|---|---|
| 1 | Better equipment and facilities | 9 | Yes |
| 2 | More staff training and education | 9 | No[1] |
| 3 | Better knowledge of lameness detection/mobility scoring | 5 | Yes |
| 4 | Having more time to implement practices | 5 | No[2] |
| 5 | Affordability of practices | 4 | No |
| 6 | Having time available to attend workshops/seminars | 2 | No |
| 7 | Higher milk prices | 2 | No |
| 8 | Regular foot trimming | 2 | No |
| 9 | More expertise/advice available from experts | 1 | No |
| 10 | Easy practices to implement | 1 | No |
| 11 | Better record keeping | 1 | No |
| 12 | Tax credits or low interest loans | 1 | No |
| 13 | Resources from industry bodies | 1 | No |
| 14 | Extra staff | 1 | No |
| 15 | Provide more staff encouragement for identification of lame cows | 1 | No |
| 16 | Reliable service | 1 | No |
| 17 | Readily available service | 1 | No |
| 18 | Better farm worker patience when handling dairy cows | 1 | No |
| 19 | More knowledge on how to treat early lameness | 1 | No |
| 20 | More knowledge about various foot lesions to be better at diagnosis | 1 | No |

[1]Overlaps with number 2 from Table 4, [2]Overlaps with number 3 from Table 4

Table 8-59: Control beliefs identified from the question 'What factors or circumstances would make it difficult or prevent you from improving the management of foot lesions causing lameness in your dairy herd over the next 12 months?' Those marked 'Yes' are considered the modal salient beliefs that will be used in the second, larger questionnaire.

| No. | Beliefs identified | No. dairy farmers | Include in questionnaire |
|---|---|---|---|
| 1 | Cost outweighs benefit | 14 | Yes |
| 2 | Lack of skills/knowledge/training | 10 | Yes |
| 3 | Lack of time available to implement practices | 8 | Yes |
| 4 | Lack of equipment/facilities | 4 | No |
| 5 | Staff failing to implement changes | 2 | No |
| 6 | Lack of support | 1 | No |
| 7 | If the Australian dollar was to rise/impact tourism | 1 | No |

Table 8-60: Normative beliefs identified from the question 'Are there any individuals or groups who would approve or think you should improve the management of foot lesions causing lameness in your dairy herd over the next 12 months?' Those marked 'Yes' are considered the modal salient beliefs that will be used in the second, larger questionnaire.

| No. | Beliefs identified | No. dairy farmers | Include in questionnaire |
|---|---|---|---|
| 1 | Animal welfare groups | 11 | Yes |
| 2 | Consumers | 7 | Yes |
| 3 | Staff | 6 | Yes |
| 4 | Visitors/tourists | 4 | Yes |
| 5 | Family | 4 | No |
| 6 | Industry bodies (e.g. Dairy Australia) | 4 | No |
| 7 | Community/the public | 2 | No |
| 8 | The media | 2 | No |
| 9 | Veterinary school | 1 | No |
| 10 | DAGS committee | 1 | No |
| 11 | Myself | 1 | No |
| 12 | Every producer | 1 | No |
| 13 | Our veterinarian | 1 | No |
| 14 | No answer provided | 3 | NA |

Table 8-61: Normative beliefs identified from the question 'Are there any individuals or groups who would disapprove or think you should not improve the management of foot lesions causing lameness in your dairy herd over the next 12 months?' Those marked 'Yes' are considered the modal salient beliefs that will be used in the second, larger questionnaire.

| No. | Beliefs identified | No. dairy farmers | Include in questionnaire |
|---|---|---|---|
| 1 | Other farmers | 6 | Yes |
| 2 | Staff | 3 | No |
| 3 | Neighbours | 1 | No |
| 4 | No answer provided | 10 | NA |

## 8.20. Appendix 20: Indirect statements for questionnaire

**Behavioural beliefs (Attitude)**

1. Improving my current management practices of foot lesions will improve dairy cow welfare.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

2. If I improve my current management practices of foot lesions, milk production will increase.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

3. Improving my current management practices of foot lesions will reduce the associated costs (e.g. veterinary consults, treatment, drugs, loss of milk).

   Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

4. Making improvements to my current management practices of foot lesions will not be worth the potential cost involved.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

5. Making improvements to my current management practices of foot lesions will be too time consuming.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

**Normative beliefs (Subjective norms)**

6. Visitors and tourists to the farm would think that

I should ___1__:___2__:___3__:___4__:___5__:___6__:___7__ I should not

improve my current management practices of foot lesions in dairy cows.

7. Animal welfare groups would
   approve___1__:___2__:___3__:___4__:___5__:___6__:___7__: disapprove

if I improved my current management practices of foot lesions in dairy cows.

8. Consumers of dairy products would think that

I should ___1__:___2__:___3__:___4__:___5__:___6__:___7__ I should not

improve my current management practices of foot lesions in dairy cows.

9. My staff members would

approve___1__:___2__:___3__:___4__:___5__:___6__:___7__: disapprove

if I improved my current management practices of foot lesions in dairy cows.

10. Other dairy farmers would think that

I should ___1__:___2__:___3__:___4__:___5__:___6__:___7__ I should not

improve my current management practices of foot lesions in dairy cows.

**Control beliefs (Perceived behavioural control)**

11. Having better equipment and facilities available would make it

easier ___1__:___2__:___3__:___4__:___5__:___6__:___7__ more difficult

to improve my current management practices of foot lesions in dairy cows.

12. Having better knowledge and training would make it

easier ___1__:___2__:___3__:___4__:___5__:___6__:___7__ more difficult

to improve my current management practices of foot lesions in dairy cows.

13. If staff members do not recognise the benefits of implementing practices it becomes

easier ___1__:___2__:___3__:___4__:___5__:___6__:___7__ more difficult to improve my

current management practices of foot lesions in dairy cows.

14. If I had more time available to implement practices/changes, I would be

more likely___1__:___2__:___3__:___4__:___5__:___6__:___7__ less likely

to improve my current management practices of foot lesions in dairy cows.

15. If the benefits of implementing practices outweigh the costs I would be

more likely___1__:___2__:___3__:___4__:___5__:___6__:___7__ less likely

to improve my current management practices of foot lesions in dairy cows.

## 8.21. Appendix 21: Direct and intention statements for questionnaire

**Attitude**

1. For me, making improvements to my current management practices of foot lesions in the next 12 months would be

Good :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Bad

Useful :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Useless

Unimportant :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Important

Desirable :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Undesirable

Valuable :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Worthless

**Subjective norm**

2. Individuals who influence my behaviour would think that I should make improvements to my current management practices of foot lesions in the next 12 months

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

3. Individuals who are important to me would think that I should make improvements to my current management practices of foot lesions in the next 12 months

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

4. Individuals whose views are important to me would approve if I made improvements to my current management practices of foot lesions in the next 12 months

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

**Perceived behavioural control**

5. I am confident that I could make improvements to my current management practices of foot lesions in the next 12 months if I wanted to

Strongly disagree :__1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

6. For me to make improvements to my current management practices of foot lesions in the next 12 months would be

Easy :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Difficult

7. How much control do you believe you have over the decision to make improvements to your current management practices of foot lesions in the next 12 months

No Control : ___1__:___2__:___3__:___4__:___5__:___6__:___7__: Complete Control

**Intention**

8. I want to make improvements to my current management practices of foot lesions in the next 12 months

Strongly disagree :__1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

9. I intent to make improvements to my current management practices of foot lesions in the next 12 months

Strongly disagree :__1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

10. It is likely that I will make improvements to my current management practices of foot lesions in the next 12 months.

Very likely:___1__:___2__:___3__:___4__:___5__:___6__:___7__: Not at all

## 8.22. Appendix 22: First draft of questionnaire

**Understanding dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness in dairy cows: Questionnaire**

**Section 1**

1. What is your age?
2. What is your gender? (*Click on appropriate box*).

☐ Male ☐ Female

3. How many years of experience do you have working with dairy cows?
4. How many years have you been managing your current dairy farm?
5. How many full time employees work on your dairy farm (directly with the dairy cows)?
6. What breed(s) of cow(s) do you keep?
7. How many milking cows (exclude heifers that have not calved yet) are in your herd?
8. What is your annual milk yield
9. On average, how many lame milking cows do you see in a year?
10. Do you observe a seasonal effect (i.e. most cows are lame in winter or summer?) If yes, when?
11. Who is responsible for treating these lame cows?
12. Over the past five years, has the occurrence of lame cows on your farm become (*Click on appropriate box*)

☐Much worse

☐Somewhat worse

☐Remained the same

☐Somewhat improved

☐Become much better

**Section 2**

The following statements refer to **your intentions to make improvements to your current management practices of foot lesions causing lameness in your dairy herd in the next 12 months**.

In terms of making improvements, consider what changes you might make to your current management practices. This includes any new or improved action that you might start doing over the next year that can:

- Improve your ability to detect cows with foot lesions in your herd.
- Improve the ability to make a correct diagnosis of a foot lesion in a cow.
- Reduce the overall occurrence of foot lesions in your herd.
- Shorten the amount of time that it takes for a cow to recover from a foot lesion.

The following provides some examples of changes that you might consider to start doing over the next 12 months:

**Current management practice:** No hoof trimming performed; maintenance hoof trimming performed only once per year; hoof trimming performed only as required, i.e. for treatment purposes.
**Change in management practice:** Conduct maintenance hoof trimming twice per year, i.e., every 6 months.

**Current management practice:** Currently no use of a locomotion scoring system.
**Change in management practice:** Use a locomotion scoring system daily, before or after milking, to screen for lame cows.

**Current management practice:** Holding off looking at a lame cow until tomorrow; holding off looking at a lame cow until it ‘gets worse’.
**Change in management practice:** Looking at a lame cow for foot lesions immediately upon noticing it is lame.

**Current management practice:** Staff do not receive training regarding the care of foot lesions and lameness in dairy cows (this includes attendance at industry workshops).
**Change in management practice:** Fund staff attendance to relevant workshops

**Current management practice:** Not repairing track surfaces regularly, especially after heavy rainfall.
**Change in management practice:** Regularly repair track surfaces particularly after heavy rainfall (i.e. removal of sharp rocks and/or slurry).

**Current management practice:** No dietary supplements, intended to strengthen the hoof structure, are used.
**Change in management practice:** Use a dietary supplement, such as biotin, to strengthen the hoof structure.

Each of the following statements are measured on a 7 point scale. The middle point (4) is neutral. Please highlight the number that most accurately reflects your opinion. Read the statements carefully. While some statements may sound similar, there are subtle differences in what is being asked. Please be careful to check the ends of the scale for each statement before responding.

1. Improving my current management practices of foot lesions will improve the welfare of my dairy cows.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__:  strongly agree

2. Individuals who influence my behaviour would think that I should make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__:  strongly agree

3. Making improvements to my current management practices of foot lesions in my dairy herd will be too time consuming.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__:  strongly agree

4. For me, making improvements to my current management practices of foot lesions in my dairy herd  the next 12 months would be

Valuable :___1__:___2__:___3__:___4__:___5__:___6__:___7__:   Worthless

5. Having better equipment and facilities available would make it

easier ___1__:___2__:___3__:___4__:___5__:___6__:___7__ more difficult

to improve my current management practices of foot lesions in my dairy herd.

6. Consumers of dairy products would think that

I should ___1__:___2__:___3__:___4__:___5__:___6__:___7__ I should not

improve my current management practices of foot lesions in my dairy cows.

7. For me, making improvements to my current management practices of foot lesions in my dairy herd  the next 12 months would be

Good :___1__:___2__:___3__:___4__:___5__:___6__:___7__:   Bad

8. If the benefits of implementing practices outweigh the costs I would be

more likely___1__:___2__:___3__:___4__:___5__:___6__:___7__ less likely

to improve my current management practices of foot lesions in my dairy cows.

9. It is likely that I will make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months.

Very likely:___1__:___2__:___3__:___4__:___5__:___6__:___7__:  Not at all

10. My staff members would

approve___1__:___2__:___3__:___4__:___5__:___6__:___7__: disapprove

if I improved my current management practices of foot lesions in my dairy cows.

11. For me to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months would be

Easy :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Difficult

12. If I improve my current management practices of foot lesions, milk production of my herd will increase.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

13. Individuals whose views are important to me would approve if I made improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

14. For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be

Useful :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Useless

15. Visitors and tourists to the farm would think that

I should ___1__:___2__:___3__:___4__:___5__:___6__:___7__ I should not

improve my current management practices of foot lesions in my dairy cows.

16. Improving my current management practices of foot lesions in my dairy herd will reduce the associated costs (e.g. veterinary consults, treatment, drugs, loss of milk).

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

17. I intend to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree :__1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

18. Having better knowledge and training would make it

easier ___1__:___2__:___3__:___4__:___5__:___6__:___7__ more difficult to improve my current management practices of foot lesions in my dairy cows.

19. How much control do you believe you have over the decision to make improvements to your current management practices of foot lesions in your dairy herd in the next 12 months

No Control : ___1__:___2__:___3__:___4__:___5__:___6__:___7__: Complete Control

20. Other dairy farmers would think that

I should ___1__:___2__:___3__:___4__:___5__:___6__:___7__ I should not

improve my current management practices of foot lesions in my dairy cows.

21. Making improvements to my current management practices of foot lesions in my dairy herd will not be worth the potential cost involved.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

22. If I had more time available to implement practices/changes, I would be

more likely___1__:___2__:___3__:___4__:___5__:___6__:___7__ less likely

to improve my current management practices of foot lesions in my dairy cows.

23. Individuals who are important to me would think that I should make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

24. For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be

Unimportant :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Important

25. If staff members do not recognise the benefits of implementing practices it becomes

easier ___1__:___2__:___3__:___4__:___5__:___6__:___7__ more difficult

to improve my current management practices of foot lesions in my dairy cows.

26. I am confident that I could make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months if I wanted to

Strongly disagree :__1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

27. Animal welfare groups would
approve___1__:___2__:___3__:___4__:___5__:___6__:___7__: disapprove

if I improved my current management practices of foot lesions in my dairy cows.

28. I want to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree :__1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

**<u>End of questionnaire. Thank you for your participation</u>**

## 8.23. Appendix 23: Dairy farmer information sheet for pilot questionnaire

Dear Dairy farmer,

I am a student from the University of Queensland completing my Master's thesis. I am currently designing a questionnaire for dairy farmers titled: Understanding dairy farmer intentions to make improvements to their management practices of foot lesions causing lameness in dairy cows. I was wondering if you would be prepared to help in finalising the design.

The expected benefits of this study will be a greater insight into dairy farmer beliefs and their intentions to improve the management of foot lesions causing lameness in their dairy herd. This insight can support policy makers, industry organisations and future research in tailoring information, training and other management strategies to assist dairy farmers in reducing the occurrence of lameness and therefore improve the welfare of their herds while benefiting from increased milk production, and reduced costs associated with lame cows.

The aims of the questionnaire are to:

i) Explore dairy farmer beliefs about improving the management of foot lesions causing lameness in their herd.

ii) Determine dairy farmer intentions to improve the management of foot lesions causing lameness in their herd in the next 12 months.

iii) Identify opportunities to increase dairy farmer intentions to improve the management of foot lesions causing lameness in their herd.

Right now we are wanting to pilot the questionnaire to see how it will be perceived by dairy farmers. Specifically we would like to know: i) if the questionnaire addresses the project aims, ii) if the questions are easy to understand and answer, and iii) if the questions are appropriate to ask dairy farmers. We are asking a small number of people to complete the pilot and provide their feedback. Thus, if you are happy to do so could you please:

Complete the questionnaire, either by using the attached document (Pilot_Questionnaire) or by using this link: https://goo.gl/forms/Tcdle3vcfwOqwwuu2, and then,

1. Comment on each of the following:

- Are any questions ambiguous or difficult to answer? Which ones?
- Does the questionnaire feel too repetitive?
- Does it feel too long?
- Whether or not you can understand all the questions – if not, what were the problems and with which questions?
- Whether the survey creates a positive impression so you think people are likely to respond – if not how could it be improved?
- Whether you think any questions were inappropriate and which ones.
- How long it took you to complete the survey.
- Add anything else that you would like to contribute.

To provide these comments you can either:

1. Write them in the provided word document (Comments_Pilot_Questionnaire)
2. Put comments directly into the questionnaire document (Pilot_Questionnaire)
3. Write them in an email (send to k.chaplin@uq.edu.au)
4. Contact me on 04 78 353 878 and I can write down your responses

**If possible, please return your responses and comments by Wednesday 8 February.**

Your comments are greatly appreciated and essential in the finalisation of this questionnaire.

Kind regards,

Kate Chaplin
MPhil Candidate -Veterinary Epidemiology
The University of Queensland
School of Veterinary Science

## 8.24. Appendix 24: Word document for comments from pilot questionnaire

**Comments for pilot questionnaire**

- Are any questions ambiguous or difficult to answer? Which ones?

Comments:

- Does the questionnaire feel too repetitive?

Comments:

- Does the questionnaire feel too long?

Comments:

- Did you understand all of the questions – if not, what were the problems and with which questions?

| Comments: |
|---|
| |

- Does the survey create a positive impression? Do you think dairy farmers are likely to respond – if not how could it be improved?

| Comments: |
|---|
| |

- Do you think any questions were inappropriate and if so, which ones?

| Comments: |
|---|
| |

- How long did it take you to complete the survey?

| Comments: |
|---|
| |

- Is there anything else that you would like to contribute?

| Comments: |
|---|
| |

**End of comments. Thank you for your time.**

## 8.25. Appendix 25: Responses for the pilot questionnaire from five dairy farmers

Table 8-62: Questions the dairy farmers were asked to respond to after completing the pilot questionnaire and their responses.

| | Dairy farmer identification and responses | | | | |
|---|---|---|---|---|---|
| Questions | Dairy farmer 1 | Dairy farmer 2 | Dairy farmer 3 | Dairy farmer 4 | Dairy farmer 5 |
| Are any questions difficult to answer? | No response | No. | Some were difficult to score because multiple factors are involved in decision making e.g. Wanting to improve is different from having the ability to improve. Other questions I thought were a bit strange e.g. I don't think any animal welfare group is not going to approve of me improving my management. | No. | No. |
| Does the questionnaire feel too repetitive? | A little. | Only a few questions. | Questions relating to those close to me or those that influence my decision making. | Somewhat. | Lots of welfare questions. |
| Does the questionnaire feel too long? | No response | No. | It took a while but my wife and I did it together. Quite a few will not respond because of its length. | Somewhat. | No. |
| Could you understand all of the questions – if not, what were the problems and with which questions? | No response | Yes. | All pretty straight forward. | Yes. | Yes. |
| Does the survey create a positive impression? Do you think other | No response | Yes. | I get the impression that the survey is skewed towards welfare aspects. Some farmers don't have | Not all farmers see lameness as a problem. | No response |

| | | | | | |
|---|---|---|---|---|---|
| dairy farmers are likely to respond – if not how could it be improved? | | | much of a problem with lameness so they tend to think lameness is not a welfare issue – I don't think they will go to the trouble of responding. | | |
| Were any of the questions were inappropriate? If so, which ones? | Why so many welfare questions? | No. | No response | Some farmers may see too much emphasis on welfare questions. | Lots of welfare questions. |
| How long it took you to complete the survey? | No response | 55 minutes. | No response | 20 minutes. | 15 minutes. |

## 8.26. Appendix 26: Final draft of questionnaire

**Understanding dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness in dairy cows: Questionnaire**

**Section 1**

1. What is your age?
2. What is your gender?

☐ Male ☐ Female

3. How many years of experience do you have working with dairy cows?
4. How many years have you been managing your current dairy farm?
5. How many full time employees work on your dairy farm (directly with the dairy cows)?
6. What breed(s) of cow(s) do you keep?
7. How many milking cows (exclude heifers that have not calved yet) are in your herd?
8. What is your annual milk yield?
9. On average, how many lame milking cows do you see in a year?
10. Do you observe a seasonal effect (i.e. most cows are lame in winter or summer?) If yes, when?
11. Who is responsible for treating these lame cows?
12. Over the past five years, has the occurrence of lame cows on your farm become

☐Much worse

☐Somewhat worse

☐Remained the same

☐Somewhat improved

☐Become much better

**Section 2**

The following statements refer to **your intentions to make improvements to your current management practices of foot lesions causing lameness in your dairy herd in the next 12 months**.

In terms of making improvements, consider what changes you might make to your current management practices. This includes any new or improved action that you might start doing over the next year that can:

- Improve your ability to detect cows with foot lesions in your herd.
- Improve the ability to make a correct diagnosis of a foot lesion in a cow.
- Reduce the overall occurrence of foot lesions in your herd.
- Shorten the amount of time that it takes for a cow to recover from a foot lesion.

The following provides some examples of changes that you might consider to start doing over the next 12 months:

**Current management practice:** No hoof trimming performed; maintenance hoof trimming performed only once per year; hoof trimming performed only as required, i.e. for treatment purposes.
**Change in management practice:** Conduct maintenance hoof trimming twice per year, i.e., every 6 months.

**Current management practice:** Currently no use of a locomotion scoring system.
**Change in management practice:** Use a locomotion scoring system daily, before or after milking, to screen for lame cows.

**Current management practice:** Holding off looking at a lame cow until tomorrow; holding off looking at a lame cow until it 'gets worse'.
**Change in management practice:** Looking at a lame cow for foot lesions immediately upon noticing it is lame.

**Current management practice:** Staff do not receive training regarding the care of foot lesions and lameness in dairy cows (this includes attendance at industry workshops).
**Change in management practice:** Fund staff attendance to relevant workshops

**Current management practice:** Not repairing track surfaces regularly, especially after heavy rainfall.
**Change in management practice:** Regularly repair track surfaces particularly after heavy rainfall (i.e. removal of sharp rocks and/or slurry).

**Current management practice:** No dietary supplements, intended to strengthen the hoof structure, are used.
**Change in management practice:** Use a dietary supplement, such as biotin, to strengthen the hoof structure.

Each of the following statements are measured on a 7-point scale. The middle point (4) is neutral. Please circle the number that most accurately reflects your opinion. Read the statements carefully. While some statements may sound similar, there are subtle differences in what is being asked. Please be careful to check the ends of the scale for each statement before responding.

1. Improving my current management practices of foot lesions will improve the welfare of my dairy cows.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

2. Individuals who influence my behaviour would think that I should make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

3. For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be

Bad :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Good

Difficult :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Easy

Useless :___1__:___2__:___3__:___4__:___5__:___6__:___7__: Useful

4. Having better equipment and facilities available would make it

more difficult ___1__:___2__:___3__:___4__:___5__:___6__:___7__ easier

to improve my current management practices of foot lesions in my dairy herd.

5. Consumers of dairy products would think that

I should not ___1__:___2__:___3__:___4__:___5__:___6__:___7__ I should

improve my current management practices of foot lesions in my dairy cows.

6. If the benefits of implementing practices outweigh the costs I would be

less likely___1__:___2__:___3__:___4__:___5__:___6__:___7__ more likely

to improve my current management practices of foot lesions in my dairy cows.

7. It is likely that I will make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months.

Not at all:___1__:___2__:___3__:___4__:___5__:___6__:___7__: Very likely

8. My staff members would

disapprove___1__:___2__:___3__:___4__:___5__:___6__:___7__: approve

if I improved my current management practices of foot lesions in my dairy cows.

9. If I improve my current management practices of foot lesions, milk production of my herd will increase.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

10. Individuals whose views are important to me would approve if I made improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

11. I intend to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree :__1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

12. Having better knowledge and training would make it

more difficult ___1__:___2__:___3__:___4__:___5__:___6__:___7__ easier

to improve my current management practices of foot lesions in my dairy cows.

13. How much control do you believe you have over the decision to make improvements to your current management practices of foot lesions in your dairy herd in the next 12 months

Complete Control: ___1__:___2__:___3__:___4__:___5__:___6__:___7__: No control

14. Making improvements to my current management practices of foot lesions in my dairy herd will not be worth the potential cost involved.

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

15. Individuals who are important to me would think that I should make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree:___1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

16. I am confident that I could make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months if I wanted to

Strongly disagree :__1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

17. Animal welfare groups would
    disapprove___1__:___2__:___3__:___4__:___5__:___6__:___7__: approve

    if I improved my current management practices of foot lesions in my dairy cows.

18. I want to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months

Strongly disagree :__1__:___2__:___3__:___4__:___5__:___6__:___7__: strongly agree

**<u>End of questionnaire. Thank you for your participation</u>**

## 8.27. Appendix 27: Details of questionnaire distribution

Table 8-63: Details describing how each dairy industry organisation distributed the questionnaire to the study population.

| Dairy organisation | Method of distribution | Specific procedure of distribution |
|---|---|---|
| DairySA | Online (newsletter) | The gatekeeper included a link to the survey in the DairySA newsletter. The link was accompanied by information contained in the Participant Information Sheet. Completion of the questionnaire implied consent. |
| DairyNSW | Online (newsletter) | The gatekeeper included a link to the survey in the DairyNSW newsletter. The link was accompanied by information contained in the Participant Information Sheet. Completion of the questionnaire implied consent. |
| NORCO | Online (email) | The gatekeeper sent an email to individuals in the NORCO database. In the email, prospective participants were initially directed to the Participant Information Sheet. If the prospective participant chose to participate, they were directed to a link to the online survey. Completion of the questionnaire implied consent. |
| AusDairyL | Online (discussion forum). | The research team created a discussion thread in the forum detailing all the information contained in the Participant Information Sheet. Prospective participants were advised on how they could participate if they choose to do so. Dairy farmers could choose to participate by completing the questionnaire (implied consent) or simply ignore the questionnaire if they declined. |
| Dairy Farmers Milk Co-operative (DFMC) | Online (email) | The gatekeeper sent an email to individuals in the DFMC database. In the email, prospective participants were initially directed to the Participant Information Sheet. If the prospective participant chose to participate, they were directed to a link to the online survey. Completion of the questionnaire implied consent. |
| Scibus | Online (email) | The gatekeeper sent an email to individuals in the Scibus database. In the email, the prospective participant was initially directed to the Participant Information Sheet. If the prospective participant chose to participate, they were directed to a link to the online survey. Completion of the questionnaire implied consent. |
| South-Coast and Highlands Dairy Co-operative | Online (newsletter) | The gatekeeper included a link to the survey in the South-Coast and Highlands Dairy Co-operative newsletter. The link was accompanied by information contained in the Participant |

| | | |
|---|---|---|
| | | Information Sheet. Completion of the questionnaire implied consent. |
| Individuals included in elicitation questionnaire | Mix of online (email) and postal (hard copy). | The dairy farmers were initially contacted by telephone, during which the researcher provided details about the questionnaire. The dairy farmers were asked if they would like to participate in the questionnaire. If they agreed, they were provided with two options to participate: i) via the online link to the survey, or ii) via a posted hard-copy that the dairy farmer could return by post once completed. For both options, the dairy farmers received a copy of the Participant Information Sheet. |

## 8.28. Appendix 28: Participant Information Sheet for questionnaire

**PARTICIPANT INFORMATION SHEET**

**Understanding dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness in dairy cows: Part 2**

**Welcome**

You are invited to participate in a study investigating dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness in their dairy herd.

**Who can participate?**

This study is aimed at **dairy farm managers (individuals responsible for making key decisions on the dairy farm) in Australia**. This questionnaire is being distributed via multiple dairy industry organisations. If you receive access to the questionnaire from multiple sources, please ensure you only respond to the questionnaire once.

**Study aim and benefits**

The aim of this study is to identify opportunities to increase dairy farmer intentions to make improvements to their current management practices of foot lesions causing lameness in their dairy herd. The expected benefits of this study will be a greater insight into what motivates and what prevents dairy farmers in terms of improving their management practices. This insight can support future research and industry organisations in tailoring information, training and other management strategies with the overall aim of improving dairy cow welfare.

**Participant involvement**

There are two parts to this study: Part 1 - a short questionnaire to identify common thoughts held by dairy farmers; and Part 2 - a second, larger questionnaire that will be designed using the thoughts identified in Part 1. This invitation to participate is for Part 2.

**What do I have to do?** If you choose to participate you will be asked to complete an online questionnaire. The survey is expected to take 20-25 minutes to complete.
**Participation and withdrawal:** Participation in this study is entirely voluntary. All participants are free to withdraw at any stage. Data from participants who choose to withdraw will be destroyed and consequently will not be included in the analyses.
**Protection of privacy:** Your confidentiality and privacy will be maintained at all times. The information that you provide will be used for the purposes of this study only. Any data used in presentations and publications will not, under any circumstances, contain characteristics that could be used for identification of individual participants. Data will be stored in a safe and secure location and only the project team will have access to this information.
**Level of risk:** There are no invasive questions or procedures, therefore there are no likely negative consequences associated with participation.

**Will I be informed of the results?**
It is anticipated that the outcomes of this study (Part 2) will result in publication in a peer reviewed journal. A report will also be prepared for the participating dairy industries who have helped distribute the questionnaire and the RSPCA. Participants will be able to obtain a copy of the completed report by contacting any member of the project team. If you wish to receive a summary of the results from this questionnaire you may contact any member of the project team (contact details below).

**Need further information?**

This study adheres to the Guidelines of the ethical review process of The University of Queensland, Australia and the *National Statement on Ethical Conduct in Human Research*. Whilst you are free to discuss your participation in this study with project team (contact details below), if you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Coordinator on +61 3365 3924.

**Project team details:**

Kate Chaplin, MPhil candidate in Veterinary Epidemiology, School of Veterinary Science, University of Queensland, Gatton, QLD, Australia. Email: kate.chaplin@uqconnect.edu.au

Tamsin Barnes, Senior Research Fellow in Veterinary Epidemiology, School of Veterinary Science, University of Queensland, Gatton, QLD, Australia. Email: t.barnes@uq.edu.au, phone: +61422980499

John (Dick) Wright, Senior Lecturer in Veterinary Anatomy, School of Veterinary Science, University of Queensland, Gatton, QLD, Australia. Email: j.wright2@uq.edu.au, phone: +61 7 5460 1962

Ahmad Rabiee, Director, Cow Signals Australia Email: a.rabiee@uq.edu.au, phone: +61423432781

## 8.29. Appendix 29: Distribution of ratings - Intention

Table 8-64: Distribution of ratings given by all dairy farmers (n = 56), and young (n = 38), old (n = 18), male (n = 43), and female (n =13) dairy farmers, using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response) for the three statements used to measure intention.

| | | Rating % | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Intention statement | Population | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| I plan to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months. | All dairy farmers | 2 | 7 | 9 | 30 | 16 | 20 | 16 |
| | Young dairy farmers | 3 | 3 | 8 | 21 | 18 | 26 | 21 |
| | Older dairy farmers | 0 | 17 | 11 | 50 | 11 | 6 | 6 |
| | Male dairy farmers | 2 | 1 | 9 | 37 | 14 | 19 | 9 |
| | Female dairy farmers | 0 | 0 | 8 | 8 | 23 | 23 | 38 |
| I intend to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months | All dairy farmers | 5 | 5 | 9 | 30 | 23 | 14 | 13 |
| | Young dairy farmers | 5 | 0 | 5 | 26 | 24 | 16 | 16 |
| | Older dairy farmers | 6 | 17 | 17 | 33 | 22 | 0 | 6 |
| | Male dairy farmers | 5 | 5 | 7 | 37 | 16 | 19 | 5 |
| | Female dairy farmers | 0 | 0 | 8 | 0 | 46 | 8 | 38 |
| I will try to make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months | All dairy farmers | 0 | 5 | 5 | 29 | 25 | 18 | 18 |
| | Young dairy farmers | 0 | 3 | 3 | 21 | 26 | 24 | 24 |
| | Older dairy farmers | 0 | 17 | 17 | 44 | 22 | 6 | 6 |
| | Male dairy farmers | 0 | 5 | 5 | 35 | 26 | 14 | 12 |
| | Female dairy farmers | 0 | 0 | 0 | 8 | 23 | 31 | 18 |

## 8.30. Appendix 30: Distribution of ratings – Direct constructs

Table 8-65: Distribution of ratings given by the 56 dairy farmers using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response) for the three statements used to measure the direct constructs, attitude, subjective norm, perceived behavioural control.

| | Rating % | | | | | | |
|---|---|---|---|---|---|---|---|
| **Direct attitude statement** | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be bad/good | 2 | 0 | 0 | 21 | 25 | 20 | 32 |
| For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be difficult/easy | 2 | 14 | 16 | 28 | 18 | 11 | 11 |
| For me, making improvements to my current management practices of foot lesions in my dairy herd the next 12 months would be useless/useful | 0 | 2 | 2 | 18 | 32 | 23 | 23 |
| **Direct subjective norm statement** | | | | | | | |
| Individuals who are important to me would make improvements to their current management practices of foot lesions in their dairy herd in the next 12 months | 0 | 9 | 7 | 37 | 20 | 14 | 12 |
| Individuals whose views are important to me would approve if I made improvements to my current management practices of foot lesions in my dairy herd in the next 12 months. | 2 | 2 | 5 | 28 | 25 | 18 | 20 |
| Individuals who are important to me would think that I should make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months. | 9 | 2 | 14 | 41 | 14 | 14 | 5 |
| **Direct perceived behavioural control statement** | | | | | | | |
| How much control do you believe you have over the decision to make improvements to your current management practices of foot lesions in your dairy herd in the next 12 months? | 3 | 5 | 7 | 25 | 28 | 18 | 12 |
| I am confident that I could make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months if I wanted to. | 2 | 0 | 5 | 18 | 20 | 14 | 41 |

## 8.31. Appendix 31: Scatterplots for overall direct attitude and each direct attitude statement

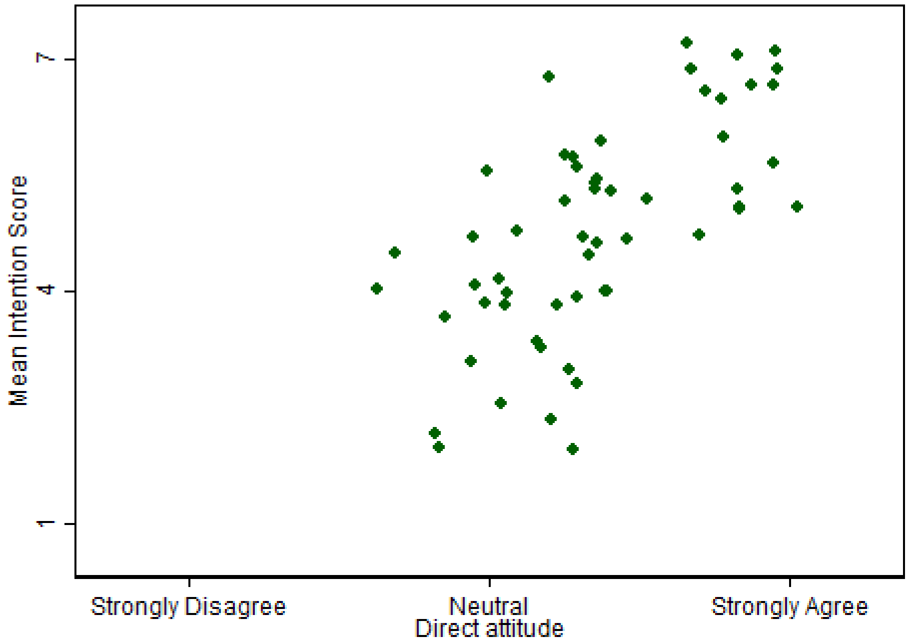


Figure 8-1: Scatterplot for overall direct attitude.

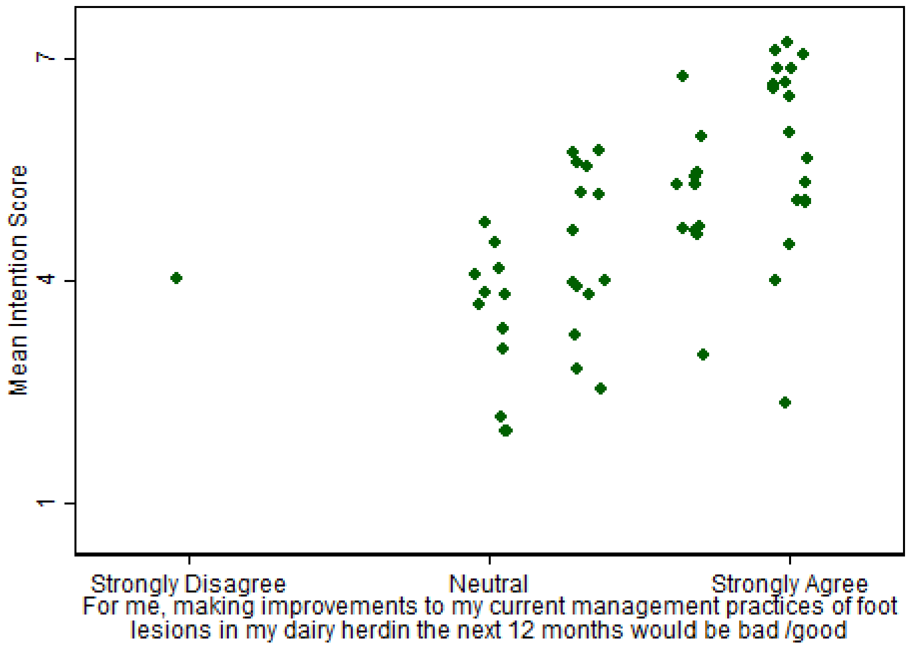


Figure 8-2: Scatterplot for the statement 'For me making improvements to my current management practices of foot lesions in my dairy herd in the next 12 months would be bad/good'.

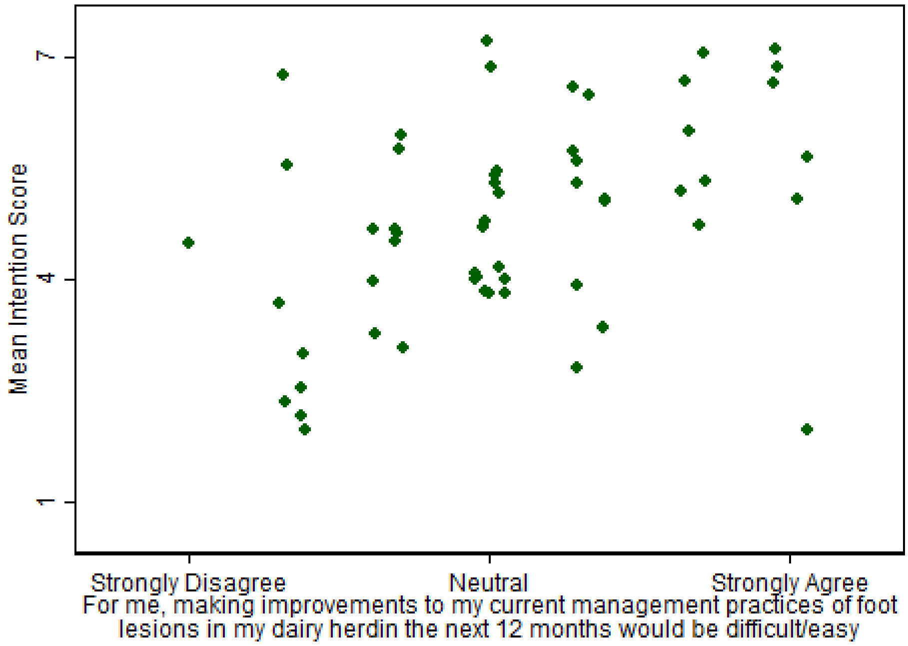


Figure 8-3: Scatterplot for the statement 'For me making improvements to my current management practices of foot lesions in my dairy herd in the next 12 months would be difficult/easy.

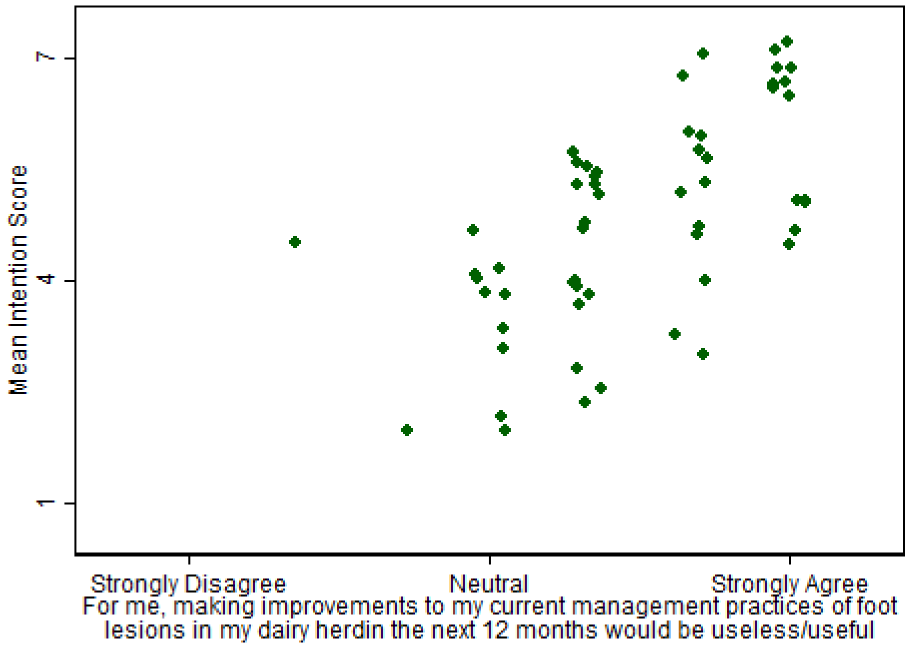


Figure 8-4: Scatterplot for the statement 'For me making improvements to my current management practices of foot lesions in my dairy herd in the next 12 months would be useless/useful.

## 8.32. Appendix 32: Scatterplots for overall direct subjective norm and each direct subjective norm statement

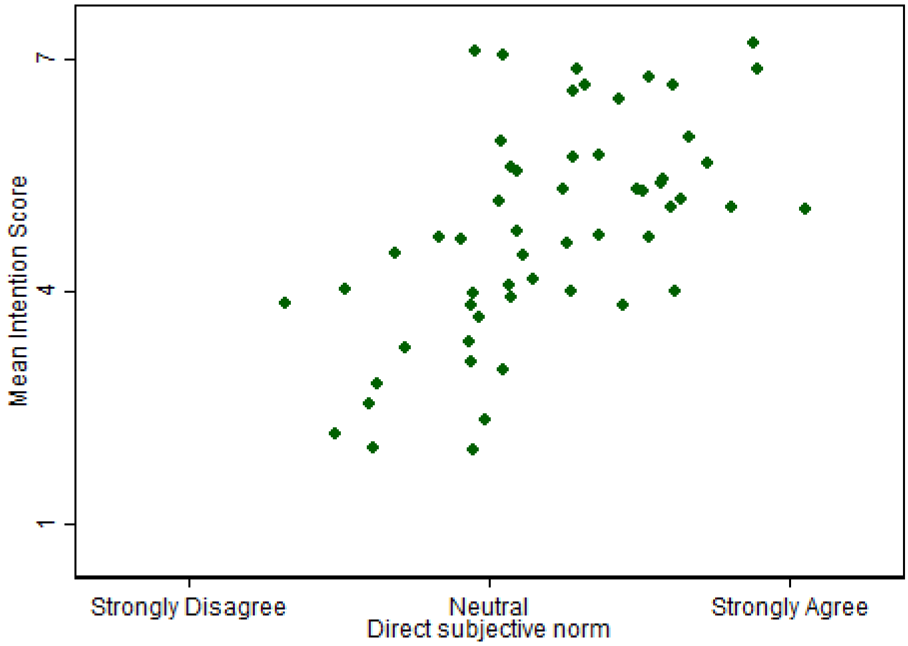


Figure 8-5: Scatterplot for overall direct subjective norm.

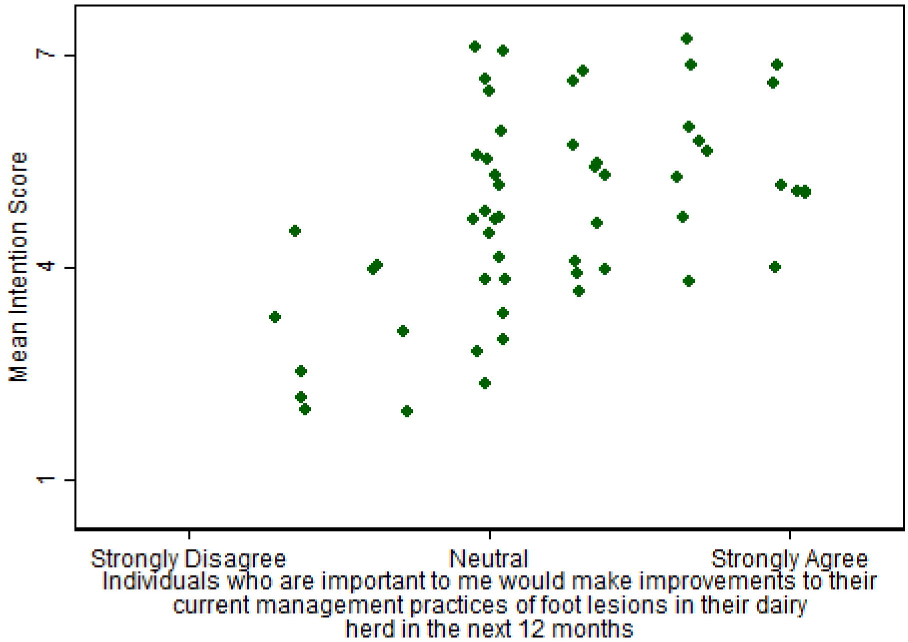


Figure 8-6: Scatterplot for the statement 'Individuals who are important to me would make improvements to their current management practices of foot lesions in their dairy herd in the next 12 months'.

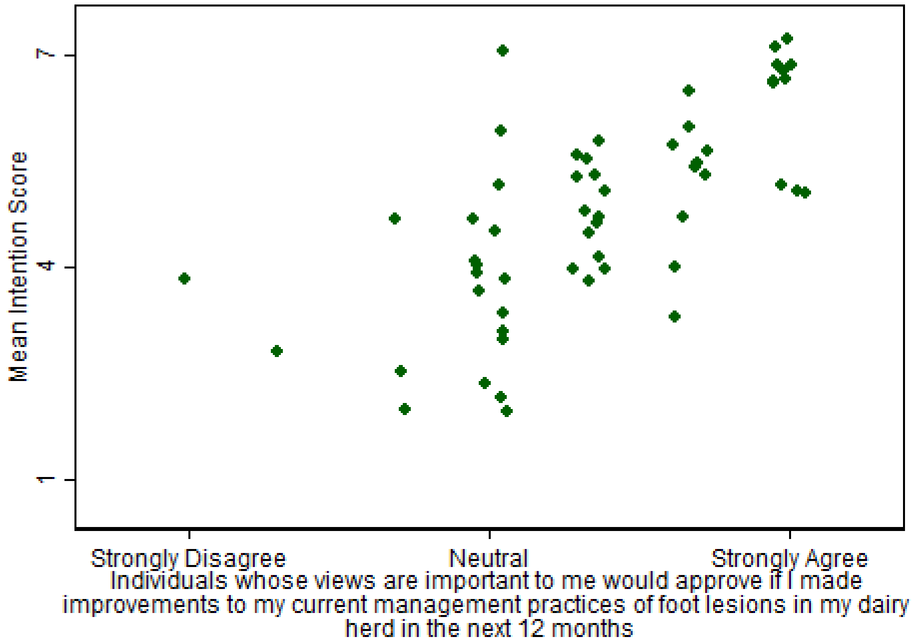


Figure 8-7: Scatterplot for the statement 'Individuals whose views are important to me would approve if I made improvements to my current management practices of foot lesions in my dairy herd in the next 12 months'.

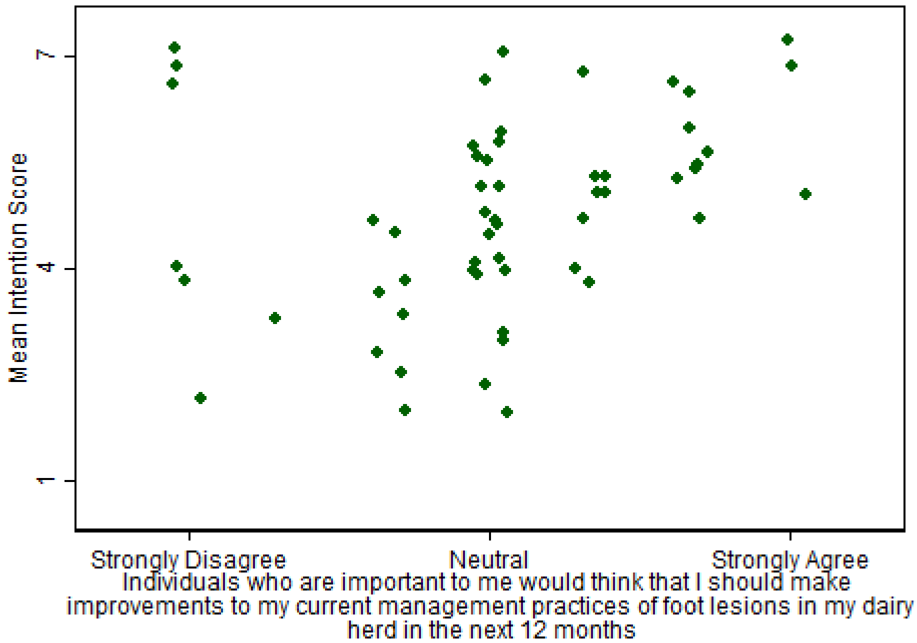


Figure 8-8: Scatterplot for the statement 'Individuals who are important to me would think that I should make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months'.

## 8.33. Appendix 33: Scatterplot for the direct perceived behavioural control statement demonstrating a significant correlation with intention

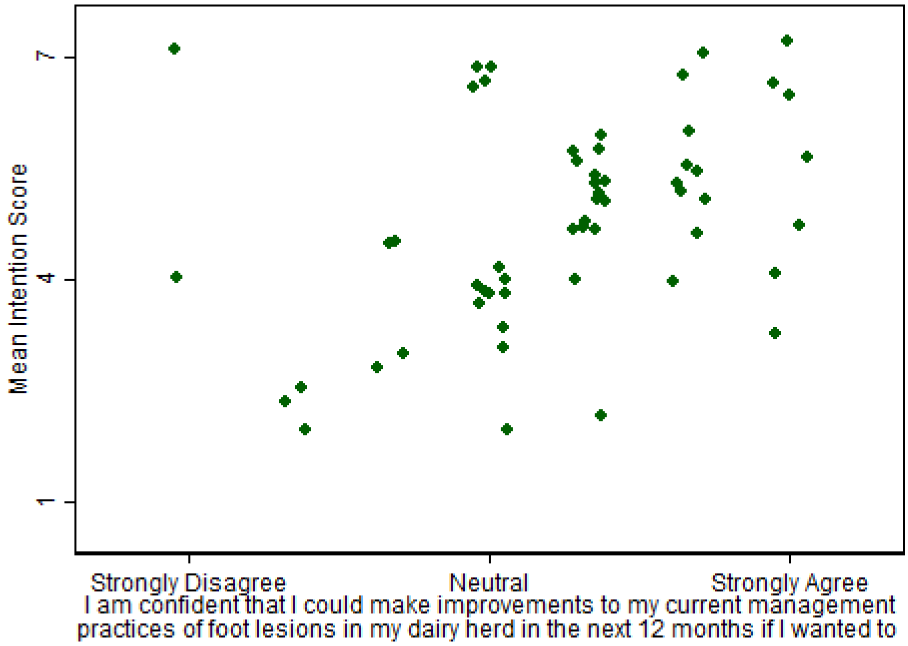


Figure 8-9: Scatterplot for the statement 'I am confident that I could make improvements to my current management practices of foot lesions in my dairy herd in the next 12 months if I wanted to'.

## 8.34. Appendix 34: Distribution of ratings – indirect constructs

Table 8-66: Distribution of ratings given by the 56 dairy farmers using a 7-point Likert scale (1 being the most negative response and 7 being the most positive response) for the three statements used to measure the indirect constructs, attitude, subjective norm, perceived behavioural control.

| | Rating % | | | | | | |
|---|---|---|---|---|---|---|---|
| **Indirect attitude statement** | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Improving my current management practices of foot lesions will improve the welfare of my dairy cows. | 0 | 5 | 2 | 23 | 25 | 20 | 25 |
| If I improve my current management practices of foot lesions, milk production of my herd will increase. | 3 | 3 | 2 | 25 | 18 | 20 | 27 |
| Making improvements to my current management practices of foot lesions in my dairy herd will not be worth the potential cost involved. | 5 | 11 | 16 | 23 | 18 | 14 | 12 |
| **Indirect subjective norm statement** | | | | | | | |
| Consumers of dairy products would think that I should not/ I should improve my current management practices of foot lesions in my dairy cows. | 2 | 7 | 9 | 32 | 12 | 20 | 18 |
| My staff members would disapprove/approve if I improved my current management practices of foot lesions in my dairy cows. | 5 | 5 | 9 | 30 | 21 | 16 | 14 |
| Animal welfare groups would disapprove/ approve if I improved my current management practices of foot lesions in my dairy cows. | 0 | 5 | 5 | 28 | 23 | 20 | 18 |
| **Indirect perceived behavioural control statement** | | | | | | | |
| Having better equipment and facilities available would make it more difficult/easier to improve my current management practices of foot lesions in my dairy herd. | 2 | 7 | 9 | 30 | 14 | 20 | 18 |
| If the benefits of implementing practices outweigh the costs I would be less likely/ more likely to improve my current management practices of foot lesions in my dairy cows. | 5 | 5 | 9 | 30 | 21 | 16 | 12 |
| Having better knowledge and training would make it more difficult/easier to improve my current management practices of foot lesions in my dairy cows. | 0 | 5 | 5 | 27 | 23 | 20 | 18 |

## 8.35. Appendix 35: Scatterplots for overall indirect attitude and each indirect attitude statement

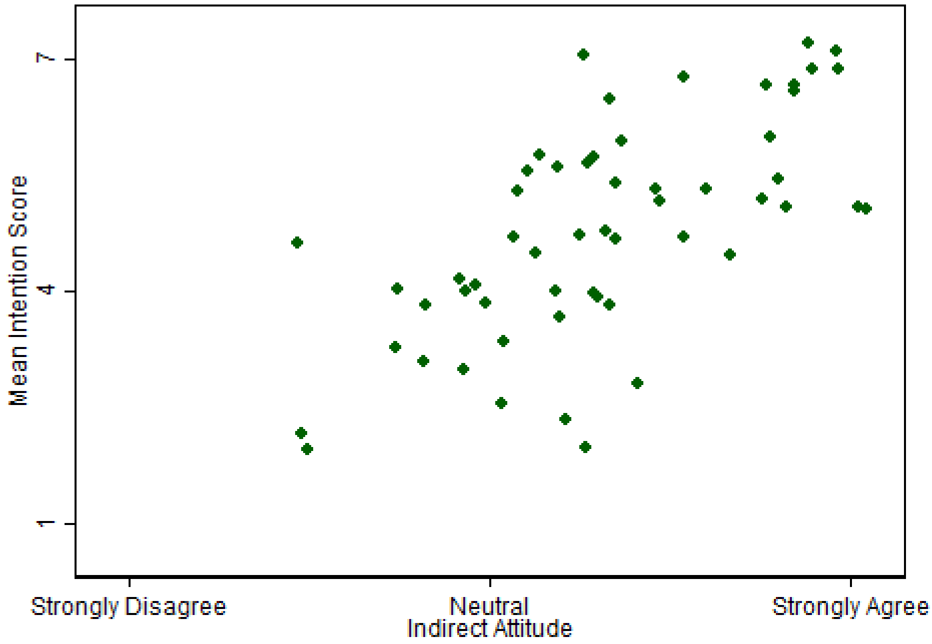


Figure 8-10: Scatterplot for overall indirect attitude.

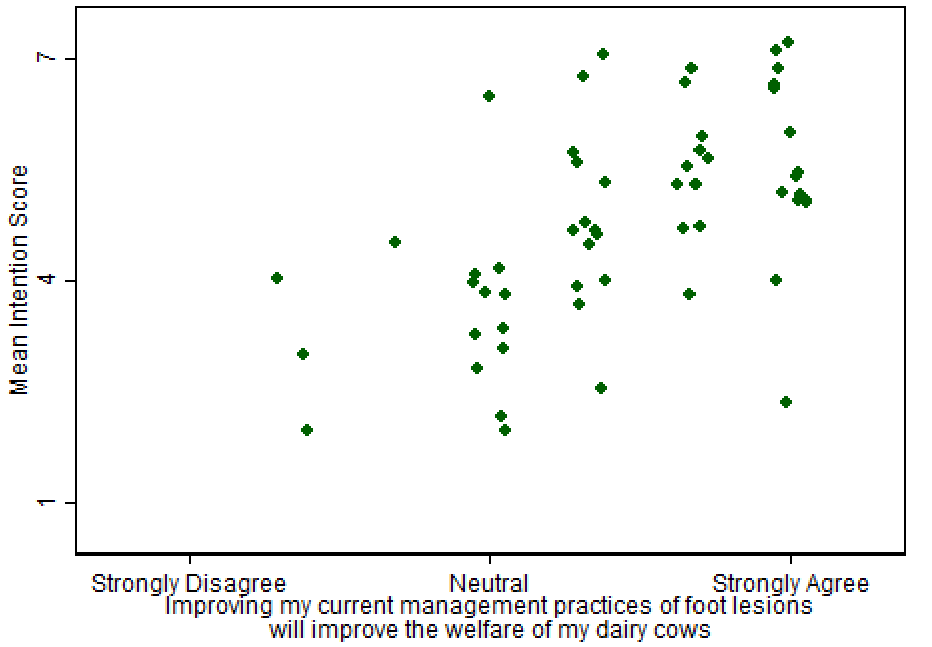


Figure 8-11: Scatterplot for the statement 'Improving my current management practices of foot lesions will improve the welfare of my dairy cows'.

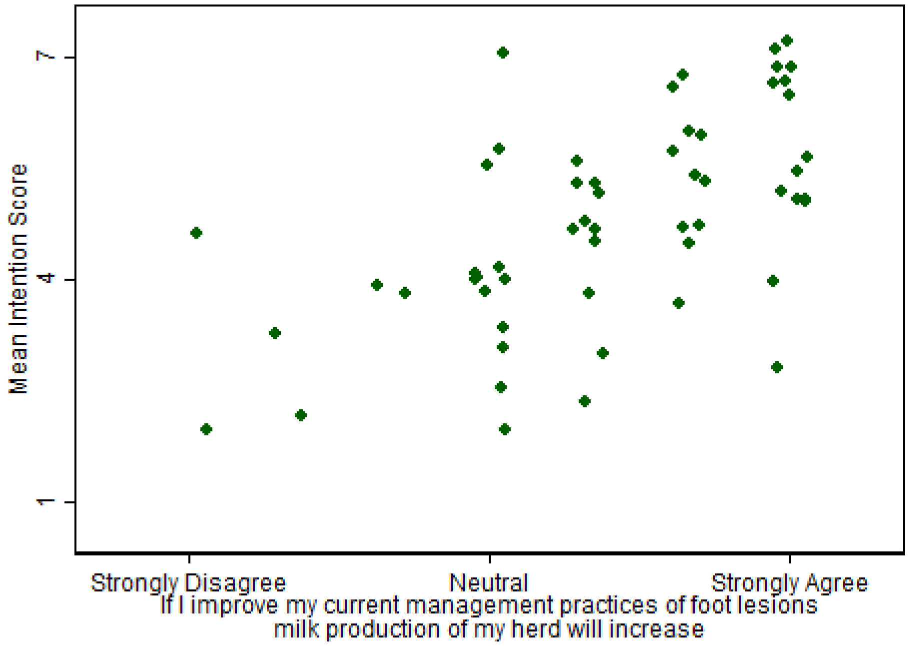


Figure 8-12: Scatterplot for the statement ‘If I improve my current management practices of foot lesions milk production of my herd will increase.

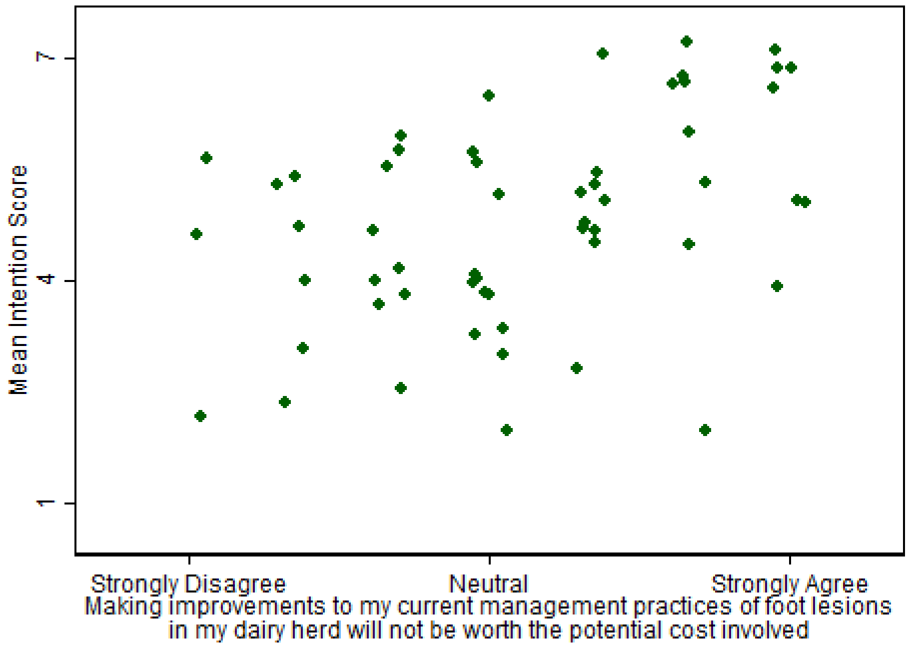


Figure 8-13: Scatterplot for the statement ‘Making improvements to my current management practices of foot lesions in my dairy herd will not be worth the potential cost involved’.

## 8.36. Appendix 36: Scatterplots for overall indirect subjective norm and each indirect subjective norm statement

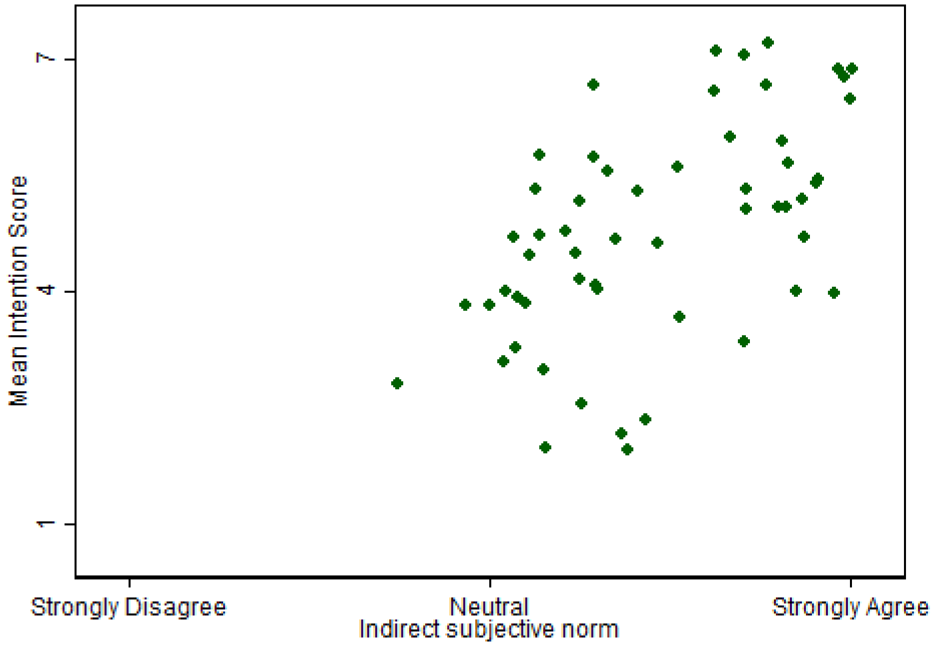


Figure 8-14: Scatterplot for overall indirect subjective norm.

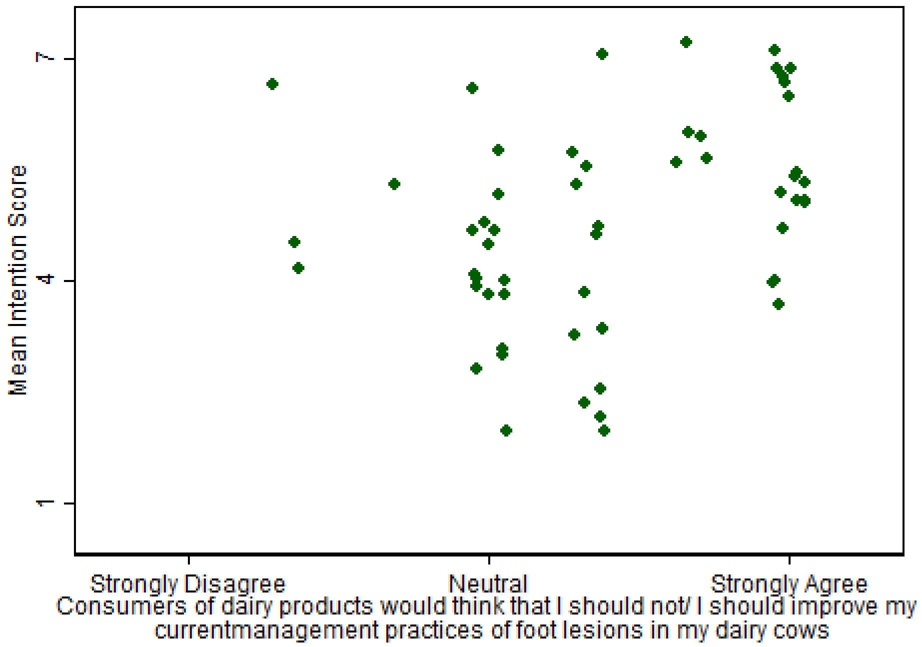


Figure 8-15: Scatterplot for the statement ‘Consumers of dairy products would think that I should not/ I should improve my current management practices of foot lesions in my dairy cows’.

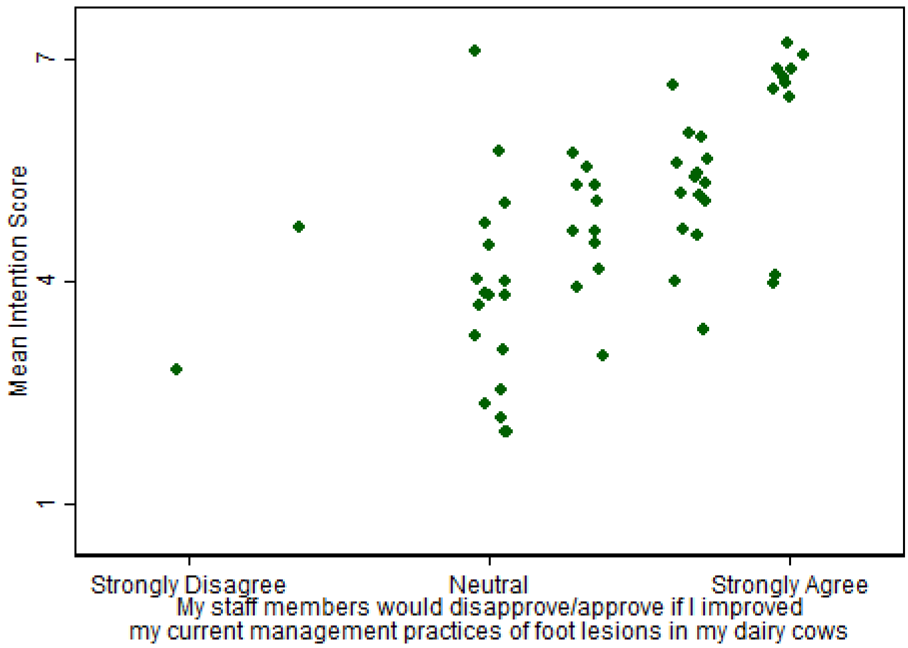


Figure 8-16: Scatterplot for the statement 'My staff members would disapprove/approve if I improved my current management practices of foot lesions in my dairy cows'.

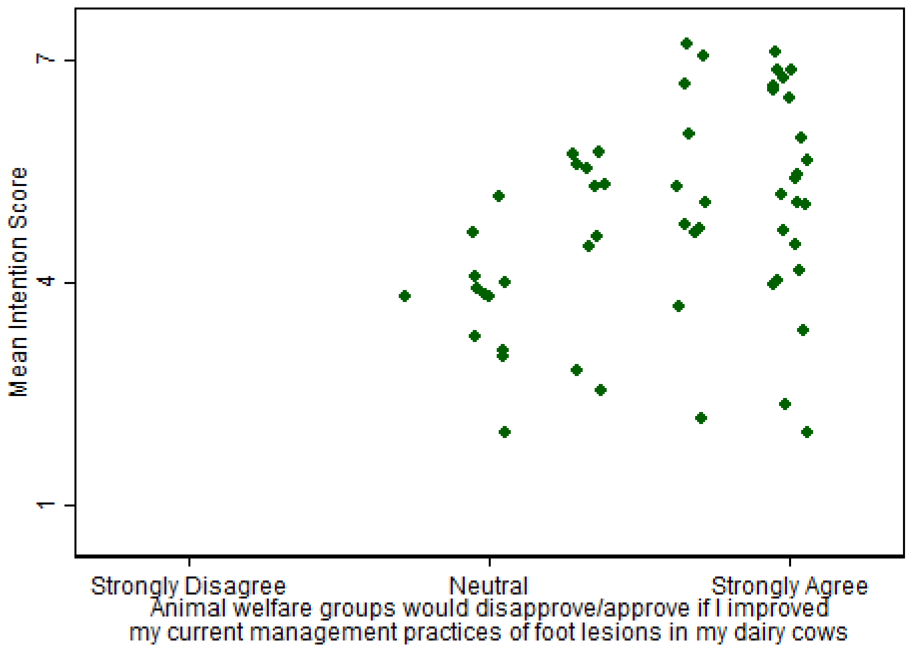


Figure 8-17: Scatterplot for the statement 'Animal welfare groups would disapprove/ approve if I improved my current management practices of foot lesions in my dairy cows'.

# 8.37. Appendix 37: Scatterplots for each direct perceived behavioural control statement.


Figure 8-18: Scatterplot for the statement ‘Having better equipment and facilities available would make it more difficult/easier to improve my current management practices of foot lesions in my dairy herd’.

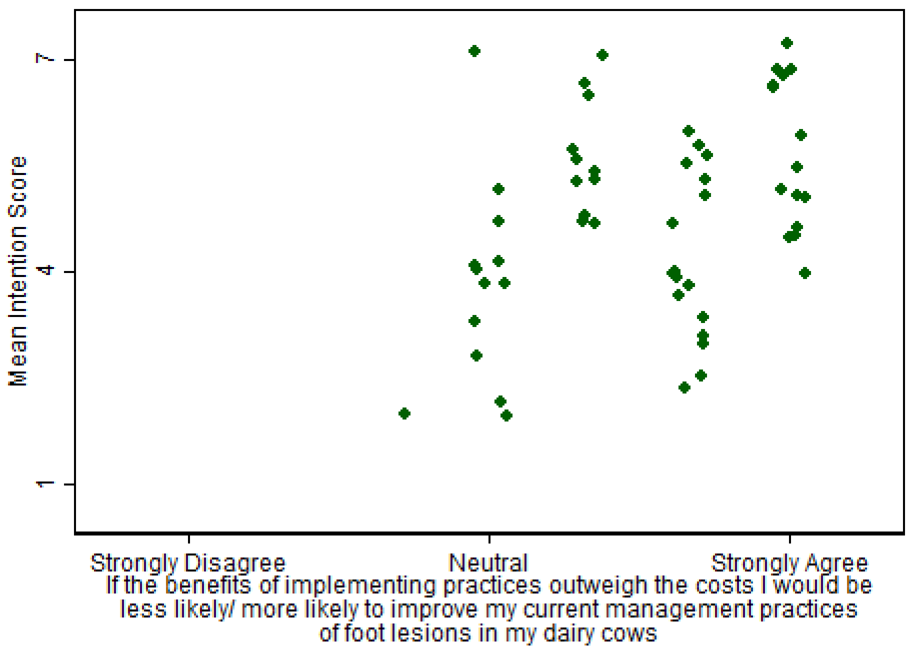


Figure 8-19: Scatterplot for the statement ‘If the benefits of implementing practices outweigh the costs I would be less likely/ more likely to improve my current management practices of foot lesions in my dairy cows’.

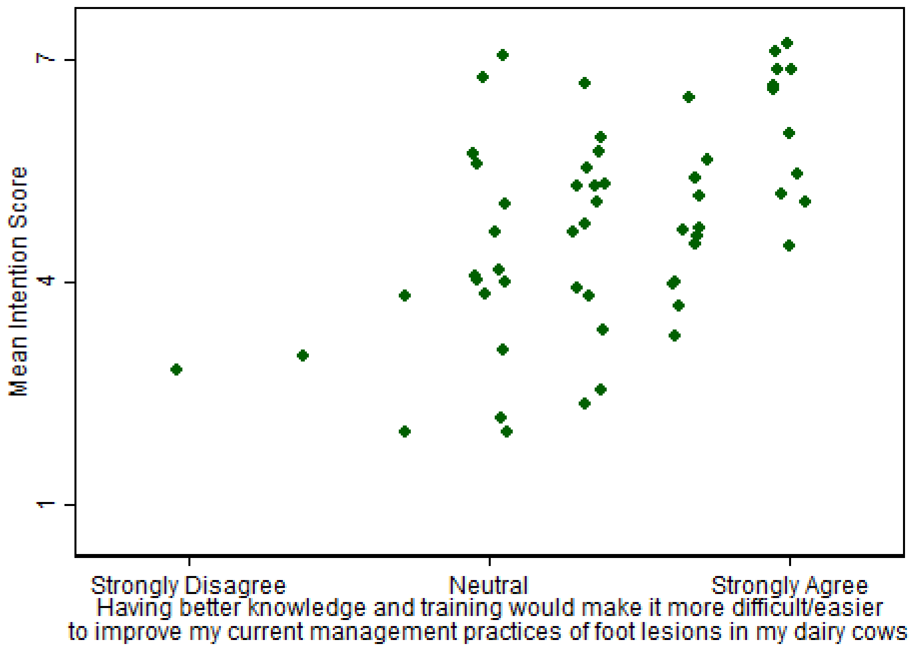


Figure 8-20: Scatterplot for the statement ‘Having better knowledge and training would make it more difficult/easier to improve my current management practices of foot lesions in my dairy cows.